PUBLIC LIBRARY

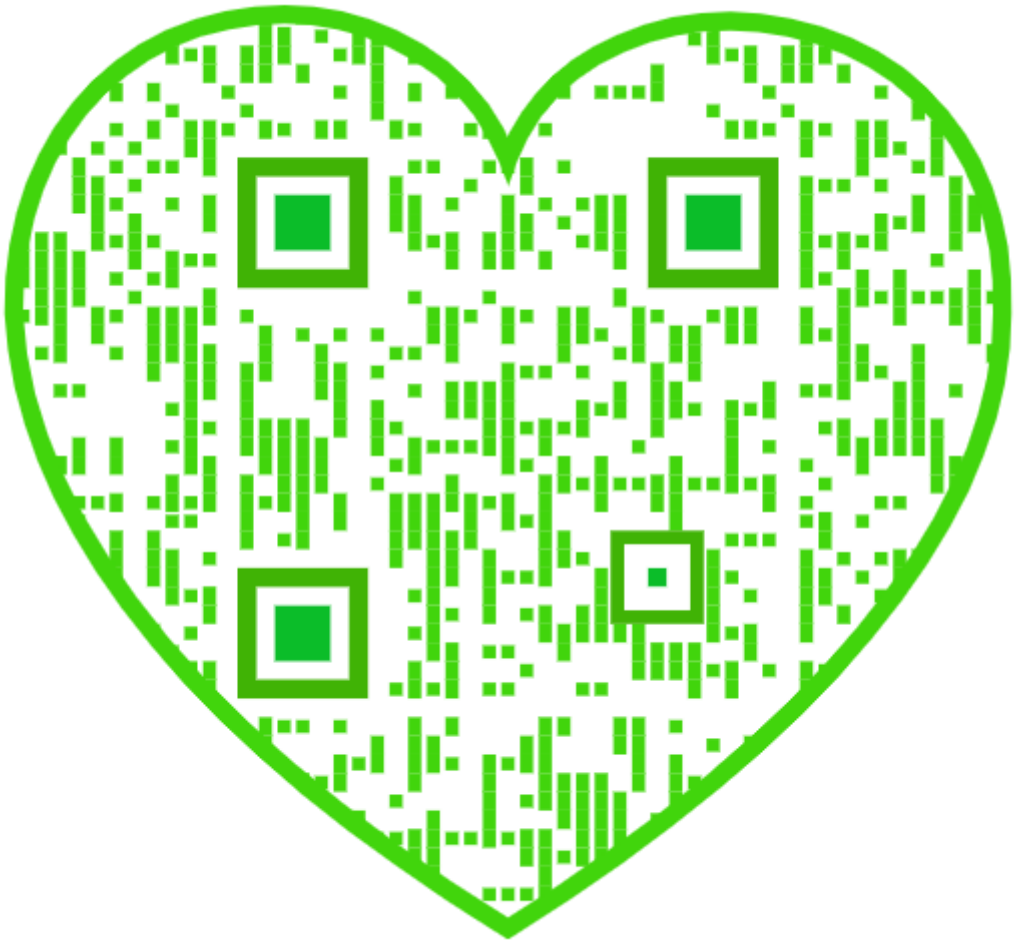
PRICE 25 CENTS

THE MANUFACTURE OF STEEL BALLS

DEVELOPMENT OF MACHINES AND METHODS

BY ROBERT H. GRANT

MACHINERY'S REFERENCE BOOK NO. 116
PUBLISHED BY MACHINERY, NEW YORK



MACHINERY'S REFERENCE BOOKS

This book is one of a remarkably successful series of 25-cent Reference Books listed below. These books were originated by MACHINERY and comprise a complete working library of mechanical literature, each book covering one subject. The price of each book is 25 cents (one shilling) delivered anywhere in the world.

CLASSIFIED LIST OF REFERENCE BOOKS

GENERAL MACHINE SHOP PRACTICE

No. 7. Lathe and Planer Tools.
No. 10. Examples of Machine Shop Practice.
No. 25. Deep Hole Drilling.
No. 32. Screw Thread Cutting.
No. 48. Files and Filing.
No. 50. Principles and Practice of Assembling Machine Tools, Part I.
No. 51. Principles and Practice of Assembling Machine Tools, Part II.
No. 57. Metal Spinning.
No. 59. Machines, Tools and Methods of Automobile Manufacture.
No. 91. Operation of Machine Tools.—The Lathe, Part I.
No. 92. Operation of Machine Tools.—The Lathe, Part II.
No. 93. Operation of Machine Tools. — Planer, Shaper, Slotter.
No. 94. Operation of Machine Tools.—Drilling Machines.
No. 95. Operation of Machine Tools.—Boring Machines.
No. 96. Operation of Machine Tools.—Milling Machines, Part I.
No. 97. Operation of Machine Tools.—Milling Machines, Part II.
No. 98. Operation of Machine Tools.—Grinding Machines.
No. 116. Manufacture of Steel Balls.
No. 120. Arbors and Work Holding Devices.

TOOLMAKING

No. 21. Measuring Tools.
No. 31. Screw Thread Tools and Gages.
No. 64. Gage Making and Lapping.
No. 107. Drop Forging Dies and Die Sinking.

HARDENING AND TEMPERING

No. 46. Hardening and Tempering.
No. 63. Heat-treatment of Steel.

JIGS AND FIXTURES

No. 3. Drill Jigs.
No. 4. Milling Fixtures.
No. 41. Jigs and Fixtures, Part I.
No. 42. Jigs and Fixtures, Part II.
No. 43. Jigs and Fixtures, Part III.

PUNCH AND DIE WORK

No. 6. Punch and Die Work.
No. 13. Blanking Dies.
No. 26. Modern Punch and Die Construction.

AUTOMATIC SCREW MACHINE WORK

No. 99. Operation of Brown & Sharpe Automatic Screw Machines.
No. 100. Designing and Cutting Cams for the Automatic Screw Machine.
No. 101. Circular Forming and Cut-off Tools for Automatic Screw Machines.
No. 102. External Cutting Tools for Automatic Screw Machines.
No. 103. Internal Cutting Tools for Automatic Screw Machines.
No. 104. Threading Operations on Automatic Screw Machines.
No. 105. Knurling Operations on Automatic Screw Machines.
No. 106. Cross Drilling, Burring and Slotting Operations on Automatic Screw Machines.

SHOP CALCULATIONS

No. 18. Shop Arithmetic for the Machinist.
No. 52. Advanced Shop Arithmetic for the Machinist.
No. 53. The Use of Logarithms—Complete Logarithmic Tables.
No. 54. Solution of Triangles, Part I.
No. 55. Solution of Triangles, Part II.

THEORETICAL MECHANICS

No. 5. First Principles of Theoretical Mechanics.
No. 19. Use of Formulas in Mechanics.

GEARING

No. 1. Worm Gearing.
No. 15. Spur Gearing.
No. 20. Spiral Gearing.
No. 37. Bevel Gearing.

GENERAL MACHINE DESIGN

No. 9. Designing and Cutting Cams.
No. 11. Bearings.
No. 17. Strength of Cylinders.
No. 22. Calculation of Elements of Machine Design.
No. 24. Examples of Calculating Designs.
No. 40. Flywheels.
No. 56. Ball Bearings.
No. 58. Helical and Elliptic Springs.
No. 89. The Theory of Shrinkage and Forced Fits.

MACHINE TOOL DESIGN

No. 14. Details of Machine Tool Design.
No. 16. Machine Tool Drives.
No. 111. Lathe Bed Design.
No. 112. Machine Stops, Trips and Locking Devices.

CRANE DESIGN

No. 23. Theory of Crane Design.
No. 47. Electric Overhead Cranes.
No. 49. Girders for Electric Overhead Cranes.

STEAM AND GAS ENGINES

No. 65. Formulas and Constants for Gas Engine Design.

SEE INSIDE BACK COVER FOR ADDITIONAL TITLES

MACHINERY'S REFERENCE SERIES

EACH NUMBER IS ONE UNIT IN A COMPLETE LIBRARY OF MACHINE DESIGN AND SHOP PRACTICE REVISED AND REPUBLISHED FROM MACHINERY

NUMBER 116

THE MANUFACTURE OF STEEL BALLS

By ROBERT H. GRANT

CONTENTS

Making the Ball Blanks - - - - - - - - - 3
Rough Grinding, Hardening and Finish Grinding - - 21
Inspecting, Gaging and Testing of Balls - - - - 39

Copyright, 1914, The Industrial Press, Publishers of MACHINERY, 140-148 Lafayette Street, New York City

CHAPTER I

MAKING THE BALL BLANKS

A review of the history of ball-making would take us back, it is claimed, more than four thousand years. The Chinese, who seem to have made everything first, are supposed to have made balls at that early date. This claim, however, is founded on a mere assumption and not on historical fact. Modern ball-making dates back to about 1870. Bicycles were then used to some extent in England, but as the bicycle was first made with a plain bearing, it was very laborious to propel; later cone bearings were introduced, and while these made the bicycle easier to work, it never became very popular until balls were used in the bearings. The first balls were made by the English workmen in their own homes, as was the custom in those days, by a very primitive method. A bar of steel of the proper size was placed in a chuck in a foot-power lathe. Then a ball was formed on the end of the bar by means of a hand tool, the long handle of which was pressed against the shoulder. The balls were made only a few thousandths of an inch larger than the finished size. They were then hardened and ground. The grinding was done between two cast-iron plates about eighteen inches in diameter. These plates were provided with concentric circular grooves, and the balls were placed in these grooves with oil and emery. The top plate was then revolved by hand; it was removed at intervals and the balls measured until found to be of the proper size. These balls were sold for 12 cents apiece. At the present time balls of the same size, and of a superior quality, can be purchased for 1/7 cent.

First Machines for Manufacturing Balls

The Simonds Rolling Machine Co., of Fitchburg, Mass., was the first company in the United States to engage in the manufacture of balls. This company was manufacturing a machine for making rolled forgings, and as by means of this machine it was possible to roll a very accurate ball, it was decided to start the manufacturing of this product. In Fig. 1 is shown a 3-inch rolling machine of the type mentioned, the size (3-inch) indicating the width of the platens. These platens run in opposite directions, and are operated by racks in the back, which, in turn, are driven by pinions on the driving shaft. The driving shaft extends to the rear of the machine where the driving gears are located. The length of the stroke is changed by the dogs *A*, which can be moved to different positions in a grooved plate, as shown. The rest *B* supports the stock while it is being rolled. The platens make about one-hundred strokes per minute.

In Fig. 2 is shown a die for rolling balls on the Simonds machine. This die is held in a shoe which is fastened to the platen. The 30-degree bev[illegible] is knurled so that when the work is rolled, it [illegible] dies, but rotate properly. The

knurling of the beveled face of the dies was one of the most important of the patents obtained by the company in connection with this development. The "invention," however, was incidental. During the early stage of the development of the machine, a workman had been trying to roll a certain piece, but the stock would keep sliding through the machine without rolling. The operator then lost patience and, determined to make the stock roll, took a cold chisel and roughed up

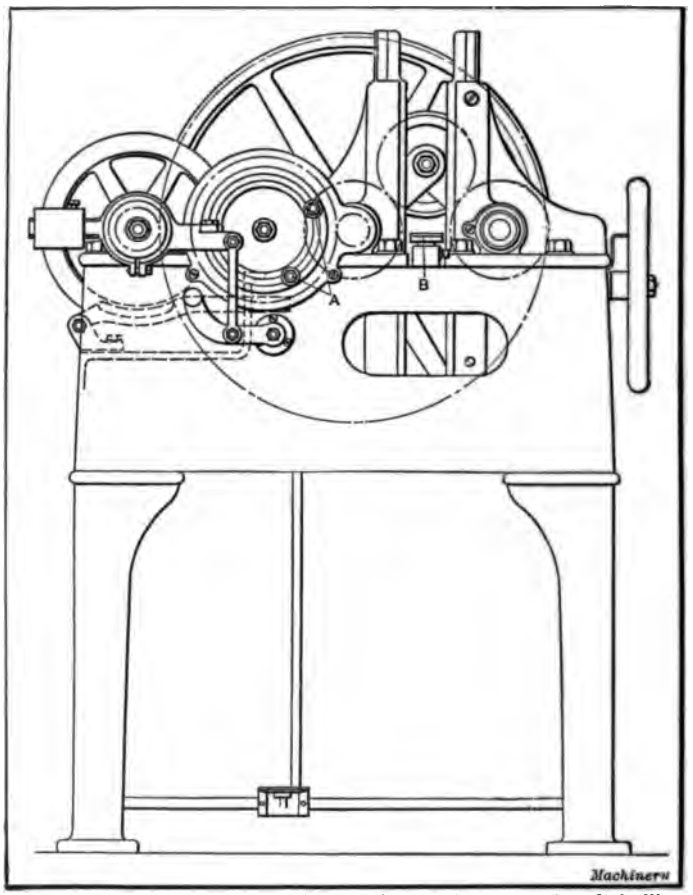


Fig. 1. Machine for Making Rolled Forgings, built by the Simonds Rolling Machine Co., Fitchburg, Mass., Some Twenty-five Years ago

the edges of the die, with the result that the die immediately produced perfect forgings. On the next set of dies made, he used a coarse knurl on the edges of the die to facilitate the proper movement of the stock. This method of knurling was patented in connection with the die, and this patent was considered one of the strongest in connection with rolling processes of this kind.

The method of rolling balls, however, is very wasteful on account of the fact that the stock which revolves over the knurled part of the die is thrown away as scrap. For every ball that is made, a diamond-shaped piece, as shown in Fig. 3, of the same diameter as the stock, has to be made and thrown away. In the illustration referred to, *A* is the stock, *B* is the ball being rolled, and *C* the diamond-shaped piece which is wasted. Hence, it will be understood that this method is very expensive when used for ball-making, although the rolling method of forging can be used to advantage on long articles where the waste is proportionately small.

In rolling methods of this kind there is a decided tendency to "pipe" the stock on account of the difference between the speed at the largest diameter and that at the "centers" of the ball, where, as a matter of fact, the metal is simply crushed and does not roll. Frequently there will then be a hole or pipe right through the center of the ball which will show after the teats at the end have been ground off. As an example of the tendency to pipe, it may be mentioned that

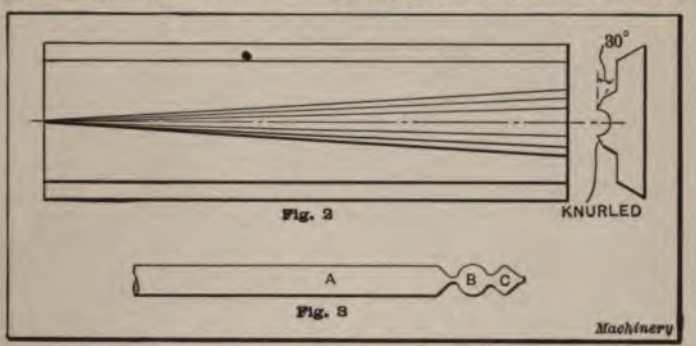


Fig. 2. Die for 3/8-inch Ball, used on Machine shown in Fig. 1.
Fig. 3. Ball and Scrap resulting from Rolling Balls

once in the writer's experience some spindles 12 inches long and 5/16 inch in diameter were rolled with pipes right through so that a string could be put through the center. For this and other reasons, although the Simonds machine was most interesting from a mechanical point of view, it had comparatively little value commercially.

Several other ball companies had no good blanking process, and, therefore, hired men who understood the rolling process from the Simonds Co. A number of machines were thus designed similar to the Simonds type. One of these had circular platens instead of straight ones, and was made with circular dies, one within the other. The die holders, of course, were running in opposite directions. This machine worked satisfactorily, but the dies were much more difficult to make on account of their circular shape, and also on account of the fact that the inner die was smaller than the outer. The company designing this machine did not have a good grinding process and the machine was, therefore, soon abandoned on account of discontinuing the manufacture of balls.

Another rolling machine constructed on the same principle was made with platens of circular form running horizontally instead of vertically. The dies were circular, but of the same diameter, and were placed on the platen near the outer periphery. There were four dies in all to take up the circumference. The platens were run in opposite directions to each other. This machine was very rapid in its action and continuous in its operation, as the dies always ran in one direction and did not have to reverse. Another rolling machine was made

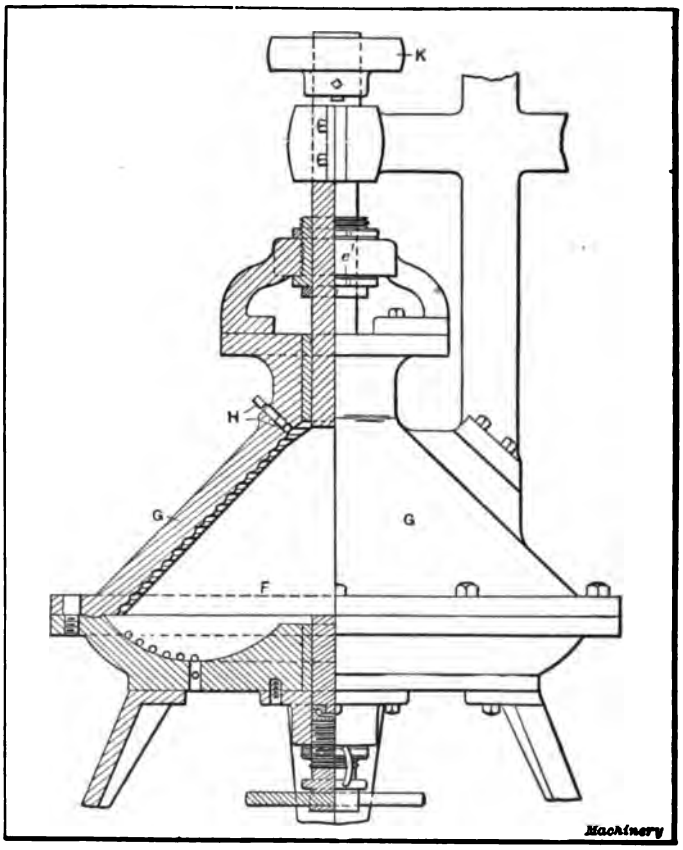


Fig. 4. The Christensen Ball Rolling Machine—U. S. Patent No. 632,836

with two small circular disks with the dies cut in the periphery. These disks were keyed to spindles which were geared together and were made to run in opposite directions. This machine worked satisfactorily on small balls, and is still used by some of the smaller ball manufacturing firms.

A number of machines have been designed from time to time for the making of ball blanks; some of these have been rather ingenious, although many of them have not been successful. In Fig. 4 is sh

a machine invented by Mr. M. F. Christensen, of Cleveland, O. The slugs or blanks *H* are fed in at the upper end of a cone-shaped device. The cone *F* revolves, being driven from pulley *K*. The inner face of the casing *G* is provided with a spiral groove from top to bottom, the section of the groove being more and more that of a complete circle as it approaches the bottom of the cone. The blank, as it runs around the cone, is supposed to be gradually rounded as it approaches the bottom. The machine, however, never proved successful for several reasons. The distance that the slugs or blanks had to travel proved a disadvantage, because if the slugs were heated, they became cold before they had passed through the device and would not compress, but were simply split open; if the slugs were not heated, the grain of the material was so distorted or crystallized that the balls could not be used. Again, if the slugs did not roll, but commenced to slide, causing clogging. the machine would have to be entirely dismantled in order to locate the trouble. Hence, after long and extensive experiments, it was abandoned.

Machines for Turning Ball Blanks

On account of the piping and burning of the steel and the difficulty of removing the teats from the balls, the manufacturers next took up the turning process for making ball blanks. The first successful machine invented was designed by the writer and is shown in Fig. 5. This machine is an automatic ball turning machine with a regular draw-back collet and automatic feed for the stock. The special feature of the machine is the manner of forming the ball. There is no turret slide or feed mechanism, but simply a solid tailstock with a heavy faceplate having a cam cut in the face, as indicated in the views at *B* and *C*. This cam is driven from cone pulley *E* through gears *H*, *J* and *K*. On the tailstock a plate with three jaws *D*, *F* and *G* is fastened, each of these jaws holding a forming tool and being provided with a roller which fits into the cam groove in the faceplate. When the machine is in operation, each jaw with its forming tool comes forward and does its share of the work (as indicated at *L*, *M* and *N*), and is then moved back to allow the next jaw to come into action. The last or third jaw cuts off the ball and rounds the end of the stock so that there will be a proper surface on which to start the cut for the next ball. Another form of turning machine was provided with a head similar to a regular plain automatic machine, having for toolholders rocker arms operated upon by a shaft at the rear of the machine. The shaft allows the arms to descend onto the stock to form the ball and then moves them back while the cutting-off tool performs its work.

The latest machine for ball turning is the Hoffmann machine shown in Fig. 6. This machine has two heads exactly alike, one at each end of the bed, these heads having regular automatic screw machine spindles. The slide in the middle of the bed is made very heavy because of being double and carrying two sets of forming tools. Four balls are formed at a time. The first ball from the stock end is about one-finished, the second one, three-fourths finished, and the third one,

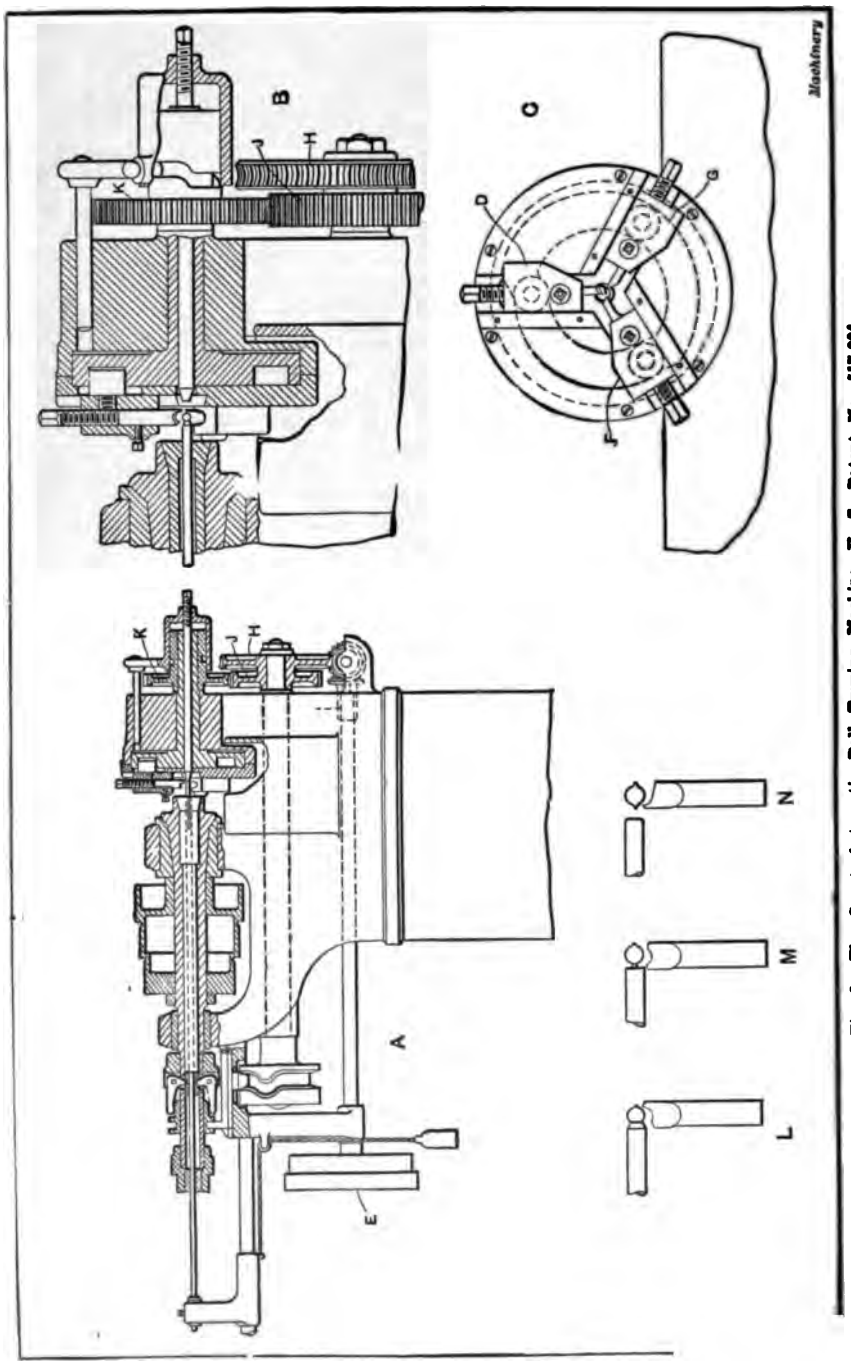


Fig. 5. The Grant Automatic Ball Turning Machine—U. S. Patent No. 517,004

completed, while the fourth ball is held in the second spindle, which is revolving at exactly the same speed as the first. This allows the forming tool to round the end of the ball so that it will be an accurate sphere. The ball is then fed on through the second spindle and drops into a pan. On account of forming four balls at a time, a roller rest

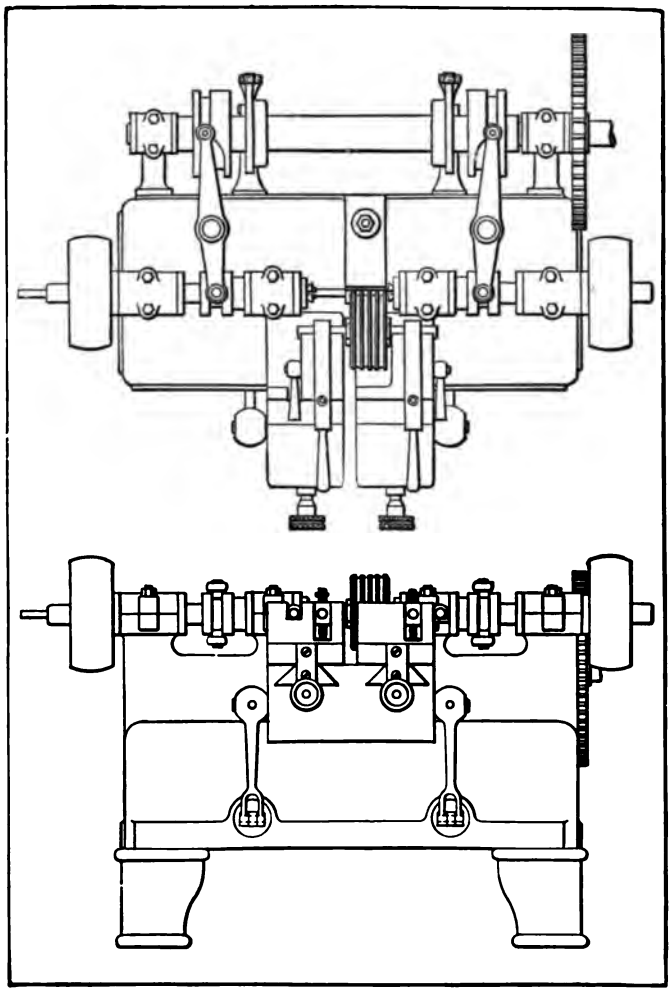


Fig. 6. The Hoffmann Ball Turning Machine—U. S. Patent No. 624,488

is used in the rear of the slide. This rest has two rollers made of hardened steel against which the stock revolves while the forming is being done. This allows the forming tool to form a perfect ball, as the stock cannot recede while the tools are at work. This is a feature of considerable value when balls are turned from tool-steel rods which it is impossible to fully anneal.

When turning balls by the method described, the stock wasted is greater than that which goes into the ball. The method is, therefore, used very little for balls over one-fourth inch in diameter, because the price of the steel becomes an important factor in the cost of manufacture when larger sizes are made. Another disadvantage is that balls cut from the bar are not as strong as when made by other methods. The direction of the grains or fibers of the steel wire is lengthwise of the bar; therefore, when the ball is formed, these fibers are cut and exposed at the surface, making a ball which is inferior in strength after hardening to balls made by other methods.

Pressing Balls

About fifteen or twenty years ago, when the bicycle business was booming, the Cleveland Machine Screw Co., which was at that time one of the largest of the firms in the country manufacturing balls, was unable to make enough blanks by the turning process, so it developed a process of pressing the ball blanks. In Fig. 7 is shown a regular wire straightener and cutting-off machine by which a coil of wire was straightened and then cut into short lengths called "slugs." This cutting-off must be very carefully done as otherwise the ball made from the slug will be of poor quality, because of the ends or ragged parts being pressed into the ball and forming a cold shut. This may fall out during the grinding or hardening operations, the ball then having a pitted appearance. The length of the slugs also must be exact, otherwise the blanks will be badly out of shape. If the slugs are not square on the ends when placed in the die, they will crowd to one side, a lopsided ball being the result.

In Fig. 8 is shown a regular No. 2 Ferracute press with an automatic attachment for pressing balls. This attachment is entirely automatic in its action, the slugs being fed down from the hopper and then conveyed by an arm to the die where the ball is pressed, after which the latter is ejected by the knock-out. At *A* is shown the hopper which holds the slugs, and at *G*, a fork which works the hopper up and down, keeping the slugs falling into the tube *B*. Fork *G* is operated through the lever *D* which is given a reciprocating motion by cam *E*. Lever *D* also moves a rack operating pinion *C*, which latter has an arm attached to it that carries the slug from the bottom of tube *B* to the dies in the press proper. The press is so timed that the slug is firmly held between the dies for a moment before the dies come together, thus giving the feeding arm time to pull away. While the pressing is being done, the arm receives another slug from tube *B*. This method of pressing is very cheap and very little material is wasted. On account of the press being of the regular open-front type, however, the blanks can be pressed only a small amount, because otherwise the machine will spring away from the work which is not heated. Hence when larger diameters are pressed, the balls are only approximately spherical, and a large quantity of stock is left for the dry grinders to remove. It has, therefore, not been found practicable to press balls by this method when they are larger than ⅜ inch in diameter.

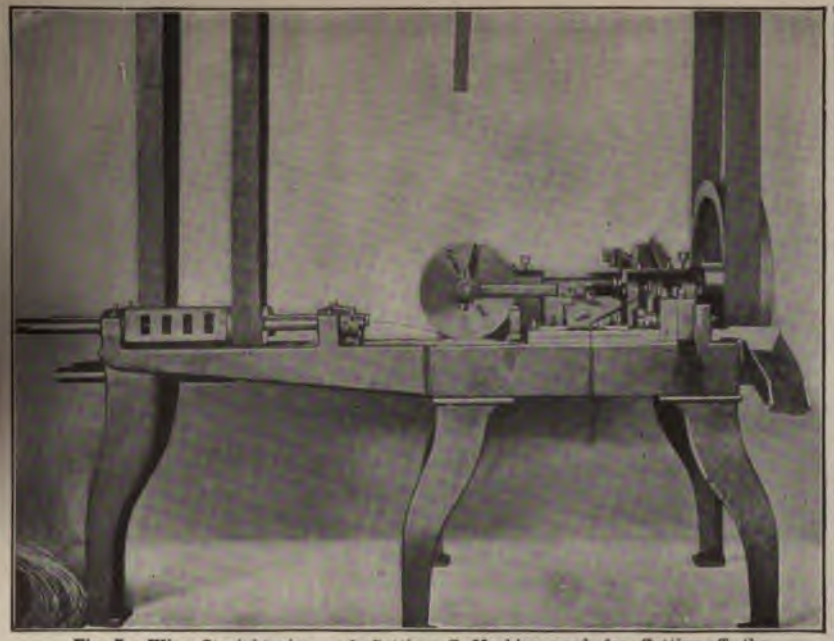


Fig. 7. Wire Straightening and Cutting-off Machine used for Cutting-off the Slugs for Pressing into Balls

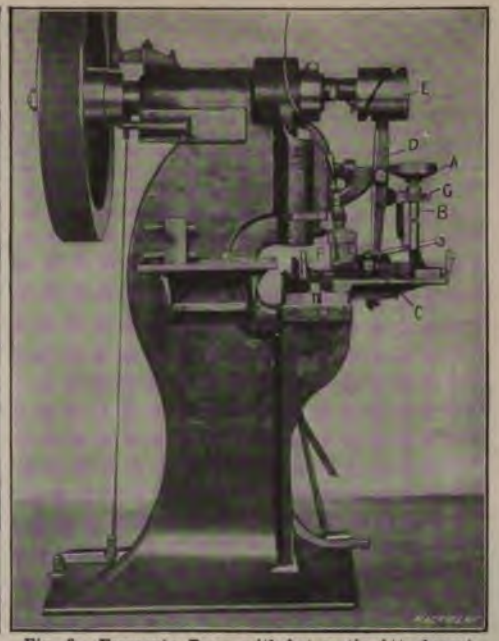


Fig. 8. Ferracute Press with Automatic Attachment for Pressing Balls

Fig. 9 shows a machine designed by Mr. M. Reid for cutting the slugs tapering at both ends, so that when pressing the ball no ragged edge can be pressed into it. The stock *A*, which comes in straight bars, is fed into the machine by gravity. Cutters *B* (shown also in Fig. 10), somewhat similar to pipe cutters, sever the stock and at the

same time taper the ends. The stock is then fed to dies *C* and *D* and the ball is formed as indicated by the various illustrations in Fig. 10. As this process is done with heated stock, a very good blank is produced. The sharp edges usually formed when cutting off the stock, are done away with by this method, and only the central part of the ball has to be pressed up, as the tapered ends are simply rounded.

The Manville Machine

The latest and best designed machine for the manufacture of small ball blanks is made by the E. J. Manville Machine Co., Waterbury,

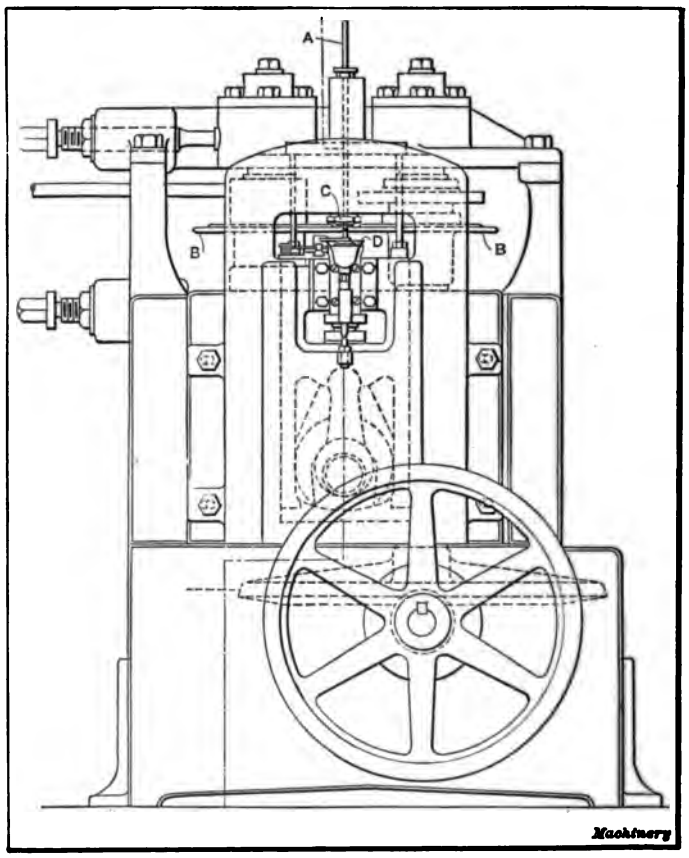


Fig. 9. The Reid Machine for Making Slugs with Tapered Ends and Pressing Balls—U. S. Patent No. 801,267

Conn. This machine has a coining-press type of frame, except that it is horizontal instead of vertical. All the work is done inside of the frame, so that a very accurate blank can be produced on account of the rigidity thus obtainable. Fig. 11 shows one of the smaller sizes

of these machines. This size is used for making balls up to ¼ inch in diameter. The stock which comes in coils is first passed through the straightening rolls *B* and then through tube *C* into the cutting-off die. Slide *E* has a cam which carries the cutting-off device or tool *F*. This cutting-off tool is flat and has spring fingers as indicated in Fig. 12. These fingers overlap the groove at the end of the cut-off tool.

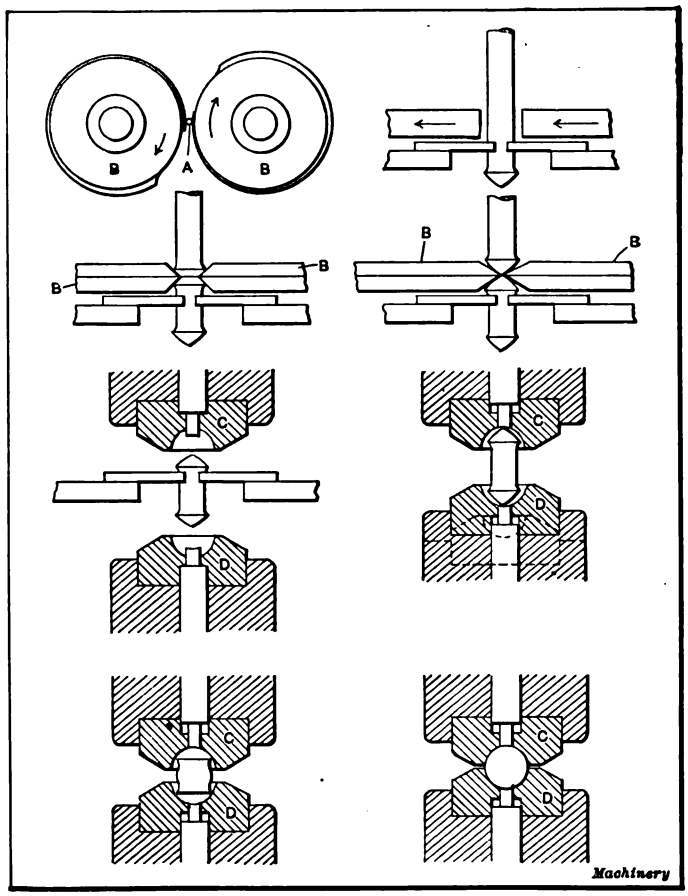


Fig. 10. Diagrammatical Views of the Various Stages of the Reid Process

After the stock has been cut off, these fingers hold the slug in position on the cut-off tool until the cam in slide *E* carries the tool with the slug over to the center of the dies. Die *G* is stationary and die *H* is mounted in movable slide *K*, which is carried forward by the eccentric on shaft *A*. As soon as the between the two dies, the cut-off *F* moves nd *H* to come together. The dies have are counter-

bored from the back to within one-half inch from the impression in the die. (See Fig. 12.) In these counterbored holes, knock-out pins are placed which are worked by levers on the under side of the machine, so that as soon as the dies draw apart these pins will knock out the ball, no matter which die holds it.

The machine is very rapid in its operation and regular 3/16-inch

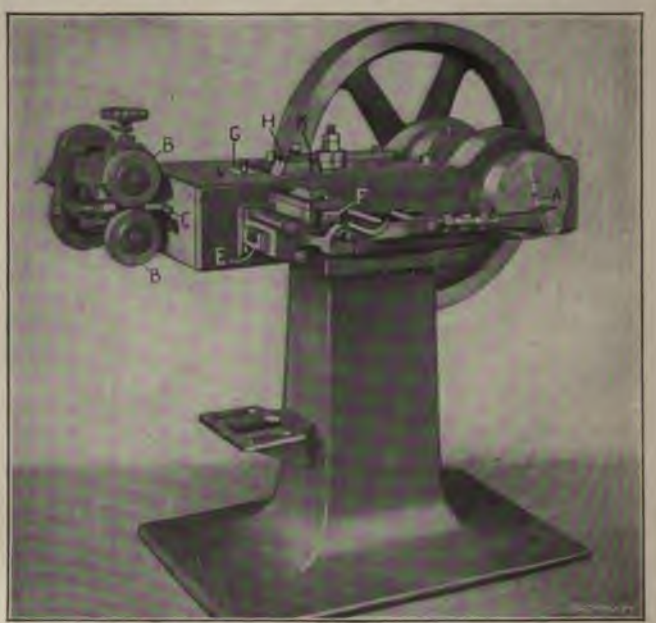


Fig. 11. The E. J. Manville Machine Co.'s Rivet Header arranged for Making Balls

balls can be made at the rate of 100,000 to 125,000 per day, according to the grade of the stock and the character of the annealing. One man can run three or four of these machines; hence the labor cost is so small as to be almost negligible. As there is no waste, this process, for smaller sizes of balls, must be deemed the best as well as the cheapest in ball manufacture at the present time. The following table gives sizes of stock used for making different sizes of balls:

Diameter of Ball, Inch	Diameter of Stock, Inch	Diameter of Ball, Inch	Diameter of Stock, Inch
1/8	0.095	9/32	0.200
5/32	0.120	5/16	0.225
3/16	0.145	3/8	0.265
7/32	0.165	7/16	0.312
1/4	0.180	1/2	0.355

Ball Forging

The best known method of making ball blanks from ⅜ inch to 2 inches in diameter is known as string forging. Fig. 13 shows a regular

upright helve hammer and a press, as well as a heating forge, the equipment being arranged for string forging. The bars from which the balls are forged are approximately 6 feet long. Twelve of these bars are put into the furnace at a time and are heated so that two sets of balls can be forged before putting the bar back into the furnace. By having a number of bars in the furnace at the same time, the heating can be done slowly and uniformly, and the bars are heated clear through to the center of the stock without burning or decarbonizing the surface. The forging of the balls requires some skill, as the bar must be turned and the hammer started at high speed, gradually slowing up as the blank begins to assume its proper shape. After being forged, the string of forged balls, indicated at *A* in Fig. 19, is placed in the trimming press where the whole row is forced through a series of holes, thus trimming

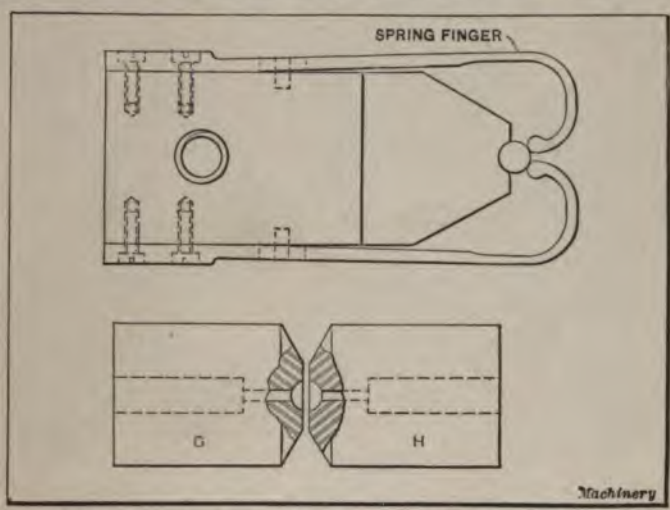


Fig. 12. Details of Cut-off Slide and Dies of Machine in Fig. 11

off the fins and separating the balls into individual blanks. The balls drop directly into a box under the press, as indicated.

Fig. 14 shows by a number of diagrammatical illustrations the manner in which the dies for string forging are made. At *A* is shown a section of a die with four impressions. The illustration also gives the notation of the die details necessary for use in connection with the following table. At *A*, for example, is indicated the diameter *D* of the cutter or cherry used in sinking the die, and also the depth *E* to which the cutter is sunk. In the view at *B* is given the distance *C* between the centers, so selected that when the proper size of stock is used, the die cavity will just be filled. It is also indicated here and at *F* that the die must be backed off or relieved on each side of the impressions, leaving only a small amount of land in the center to do the hammering. This backing off is done by moving the jig around on the milling machine or die sinking ma sinking the cutter or cherry into the die about

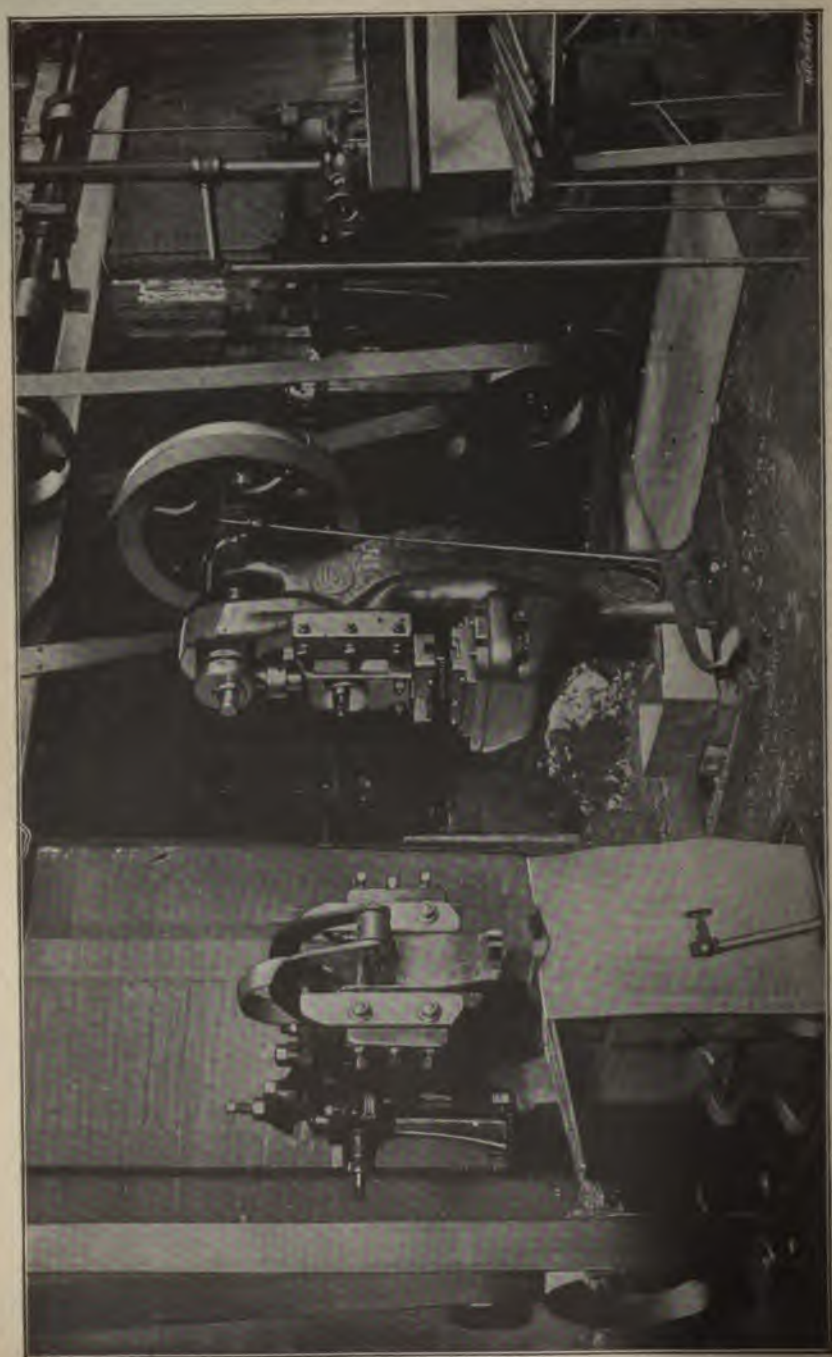


Fig. 13. Upright Helve Hammer and Press, arranged for String Forging of Balls

1/16 inch, leaving the width of the center about one-third of the diameter of the ball. At *G* is shown the depth of the bridge, which is very important, as the neck formed by the bridge must hold the balls together during the forging and not draw the stock near the neck, so as to cause a pipe, which is very easily done. At *H* is shown the size of the stock

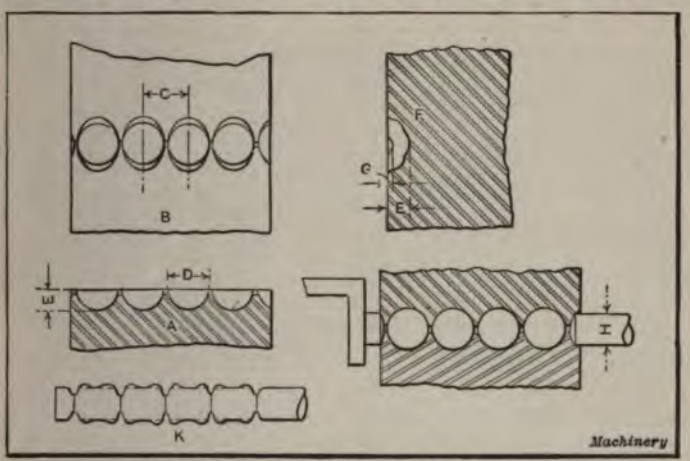


Fig. 14. Details of Dies for String Forging

which is always smaller than the diameter to be forged. The stock must be close to the required size; otherwise difficulties will be met with. If under size, the balls will not fill out; if too large, extra hammering

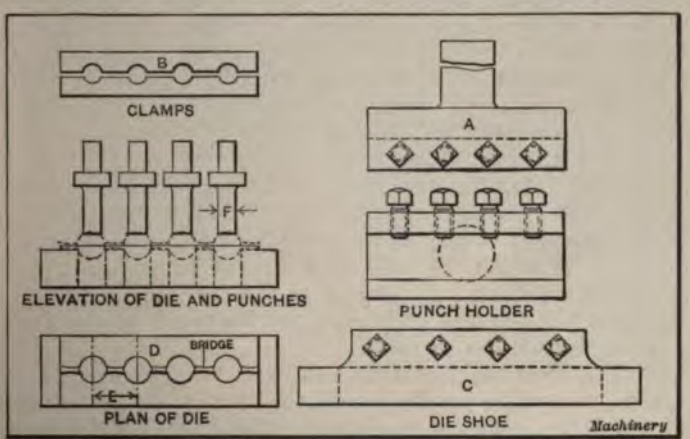


Fig. 15. Tools used for Trimming the Balls after Forging in a String

will be required, which causes the dies to soon wear out. In Fig. 14, four balls are shown forged at a time, but as this illustration is only diagr[illegible]atical. it is not implied that this is the correct number used ir[illegible]owing table gives the number of balls that would

be forged in a string for different sizes of balls, together with other dimensions required for the sinking of dies. At *K* is shown the stock after it has been slightly hammered to see if the dies are in perfect alignment. It is easily seen that when there are so many impressions in the dies, if the die warps in the hardening, the two dies will not match perfectly, and the balls at either end may be rather poor in quality. It is, therefore, very important to use a die steel that will hold its shape after hardening.

DATA FOR STRING FORGING OF BALLS
(See Fig. 14 for Notation.)

Size of Balls	Size of Stock, H	Diam. of Cutter, D	Distance Between Centers, C	Depth of Cavity, E	Depth of Bridge, G	No. of Balls
3/8	0.320	0.395	0.485	0.198	0.040	18
7/16	0.375	0.457	0.550	0.228	0.050	16
1/2	0.437	0.520	0.615	0.260	0.050	14
5/8	33/64	0.645	0.755	0.322	0.060	12
3/4	39/64	0.775	0.910	0.387	0.065	9
7/8	23/32	0.905	1.060	0.452	0.065	8
1	13/16	1.035	1.210	0.517	0.075	7

The necessary tools for the trimming of the balls are shown in Fig. 15. At *A* is shown the holder for the punches, the shank fitting into the head of the press. At *B* is shown a plate with holes drilled to the same diameter as the shanks of the punches. This plate is sawed in two, and after the punches are placed in the holes, it is clamped in holder *A* and held in place by four set-screws. The diameter *F* of the punches is about one-eighth inch less than the diameter of the balls. At *C* is shown a bolster fastened to the press and at *D* a plan of the die that is drilled with the same distance *E* between the centers of the holes as the distance between the forged balls. A groove is provided between the holes drilled in the bottom die *D* so that the necks between the balls will not touch the top of the die. Die *D* is placed in bolster *C* and lined up with the punches as in ordinary stamping processes.

The furnace used for heating the stock is of a special oil burning type. The burner is placed on the side of the furnace midway between the front and the rear. By having a special form of baffle plate directly in front of the flame, the latter is distributed throughout the furnace before it comes out at the front. An air pipe is passed under the opening through which the stock is put in to be heated. This pipe has a number of small holes drilled in the side facing the opening, and when air is forced through these holes, the heat is diverted upward and kept away from the operator.

Large balls, from 2½ inches up, are usually forged under a steam hammer. Stock of the proper diameter is first cut off to the required length and both ends are chamfered. The length of the stock is determined by the weight of the finished ball, an allowance for finishing being added. The blanks are placed in an oil furnace and allowed to heat slowly. Each time a blank is forged, a new one is put into its place in the furnace. The dies for this kind of forging are of an entirely different form from those used for string forgings. They

cupped out to the desired diameter, but are only sunk to a depth of one-quarter of the diameter of the ball to be forged, and are not backed off. When the blank is heated, the hammer man places it in the die, and the hammer is worked very slowly until the ball begins to take a spherical shape, at which time quicker and heavier blows are struck. On account of the impressions in the dies being so shallow, the opera-

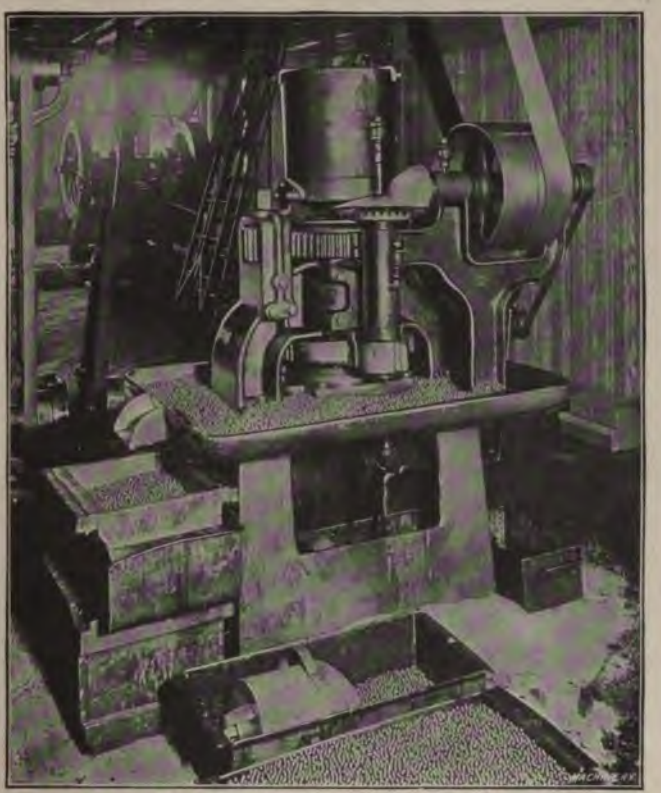


Fig. 16. "Flasher" or Rotary File used for Removing Fins from Forged Balls

tor has ample space to turn the ball in all directions, and can, therefore, produce an almost true sphere. Blanks 4 inches in diameter have been forged that have not been out of round over 0.005 or 0.006 inch.

The Flashing Process

The ball blanks as they come from the press or hammer are more or less out of shape and have a flash or fin or some other projection caused by the cutting-off or the wearing of the dies. These fins must be removed before the first grinding as they would otherwise mar the grinding rings. In Fig. 16 is shown what is known as a rotary file or flasher used for remo[illegible] these fins. The balls are fed through the

spindle by gravity and discharged from the rotary filing plates by centrifugal action. The head of the machine, which is run by a worm and worm-wheel, has a spindle to the end of which the rotary file is attached. As the spindle is hollow, the balls can be fed through it to the center of the plate. The lower plate is solid, but is adjustable up and down, allowing for different sizes of balls and for wear. The balls as they pass from the spindle to the center of the plate, are filed by the upper plate revolving and forcing them over the lower, and they

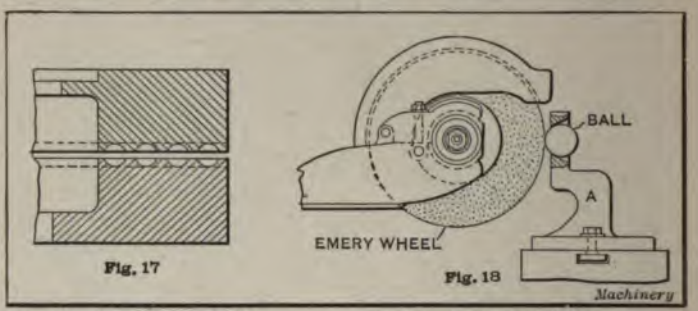


Fig. 17. Principle of Multiple Ring Grinder

Fig. 18. Method of Flashing Large Balls

fall out at the outer edge into a basket. The operation is repeated after the lower plate has been adjusted. The plates are kept from clogging by a mixture of lard and kerosene oil, circulated by a pump from a tank below to a reservoir above.

There is also another method of removing the flash or fin from the

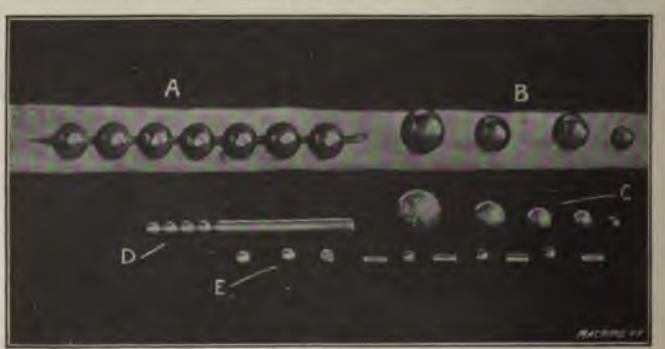


Fig. 19. Sample of Balls made by Various Processes at Different Stages of Completion

balls, known as the multiple ring grinding process. Fig. 17 shows a diagrammatical sketch of the principle of this method. Rings which are slightly grooved are placed on a heavy grinder similar to a drill press. The grooves are filled with balls and No. 36 emery or carborundum. The top ring is fastened to the spindle and allowed to revolve at a high speed while pressure is being applied. In a short time the balls are removed and found to be comparatively smooth and ready for the first dry grinding.

The larger balls are ground separately in a very simple but effective way, as indicated in Fig. 18. An upright *A* is bolted to the table of a small emery wheel grinder. This upright has a tapered hole through it into which the ball is pushed and adjusted so that the ball after the flash has been removed will barely touch the emery wheel. The operator, by means of a short pair of tongs, can turn the ball in all directions. As the ball cannot pass through the tapered hole in the upright more than a certain distance, flat spots cannot be ground, but the fin is simply removed and a smooth surface produced.

In Fig. 19 are shown a number of samples of balls made by various processes and at different stages of completion. At *A* is shown a string of forged balls, and at *B* forged balls after trimming. At *C* are shown a number of balls after being rough ground, at *D* the end of a bar operated upon in a Hoffmann ball turning machine, and at *E* a number of slugs and balls pressed from them.

Kind of Steel Used in Ball-making

The most important thing to be considered in the manufacture of balls is the quality of steel used. One of the largest elevator companies in the United States tried 432 different samples of steel, obtained in this country and abroad. Balls from these samples were made and tested by being put into actual use. From these tests it was ascertained that the two grades of steel below (carbon and alloy) are best suited for making steel balls.

1.—Carbon, 1.12; silicon, 0.015; phosphorus, 0.017; manganese, 0.19; sulphur, 0.019; chromium, 0.25 per cent.

2.—Carbon, 0.95; silicon, 0.014; sulphur, 0.019; phosphorus, 0.018; manganese, 0.025; chromium, 1.25; tungsten, 0.25 per cent.

It may be said without exaggeration that balls are used in nearly every kind of article that it is possible to name, provided it revolves. They are used in the cheapest kind of hardware and in the finest mechanisms and surveyors' instruments. Balls 1/16 inch in diameter are used in electric meters and typewriters. The number of balls being used for these purposes alone is from fifty to seventy-five millions per year. The largest balls made are about 6 inches in diameter.

CHAPTER II

ROUGH GRINDING, HARDENING AND FINISH GRINDING

In the previous chapter, the methods of making the blanks and preparing them for the dry grinding were explained. In the present chapter the grinding and hardening operations will be dealt with. The old English method of grinding the balls was mentioned in the previous chapter, the balls being ground between tw the upper one of which was revolved by hand. T or balls

in the bicycle industry soon brought about improved methods for grinding, the first step being to fasten the top plate to the spindle of a drill press, while the bottom plate rested on the table of the machine. In this way work was produced very much faster, but no better quality was obtained than formerly. About the time when the first steel balls were manufactured in this country, special grinding heads of a much more substantial character were devised. Fig. 20 shows a row of oil grinders, such as were first made in this country. The head is made in the form of a goose neck, and has three bearings. The lower, or main, bearing has a quill the same as a drill press, with a rack cut in it. A lever with pinion teeth cut on the end meshes with this rack and provides the means for raising and lowering the head. The spindle, which has a large faceplate fastened to the lower end, carries the

Fig. 20. Battery of Early Type of Ball Grinding Machines

upper grinding ring, which is fastened to the faceplate by three screws. The main drive is through a set of bevel gears on the countershaft directly over the spindle of the machine. A vertical shaft transmits the power from the countershaft to the spindle. As all the blanks at this time were either pressed or forged, instead of being turned, the amount of stock to be removed was considerably more than it is when turned ball blanks are used. For this reason the time required for grinding ¼-inch balls was from one-half to three-quarters of an hour, and if the rings were badly worn the balls would come out of the grinder considerably out of true. It was, therefore, necessary to devise a better and quicker process—a rough grinder—for removing the surface of the balls. It is especially necessary to remove the surface to some depth when the balls are forged, as the outside is then apt to be decarbonized.

The Richardson Rough Grinder

The first rough grinder for balls was made by Mr. Henry Richardson, president of the Waltham Emery Wheel Co., Watham, Mass., in 1877. Mr. Richardson, in speaking of this machine, has mentioned a few interesting facts about his experiments along this line. He took a regular 16-inch bastard file and ground a 90-degree groove in the center, almost the entire length of the file. The groove was ground clear through the file so that it would allow a 5/16-inch ball to project through to such an extent that the ball could be ground by a wheel without the latter touching the file. An emery wheel was then fastened to the faceplate of a lathe, and the file was clamped to the carriage in a vertical position. A plate with an elongated slot, which could be moved up and down on the tailstock spindle, was then made. The file with the balls was now placed against the balls. The lathe was then started. The balls at once began to move in the V-groove in the file, and by moving the plate on the tailstock spindle up and down, the balls were turned in all directions, producing in a very short time a blank which was a comparatively true sphere, fairly accurate as to dimensions.

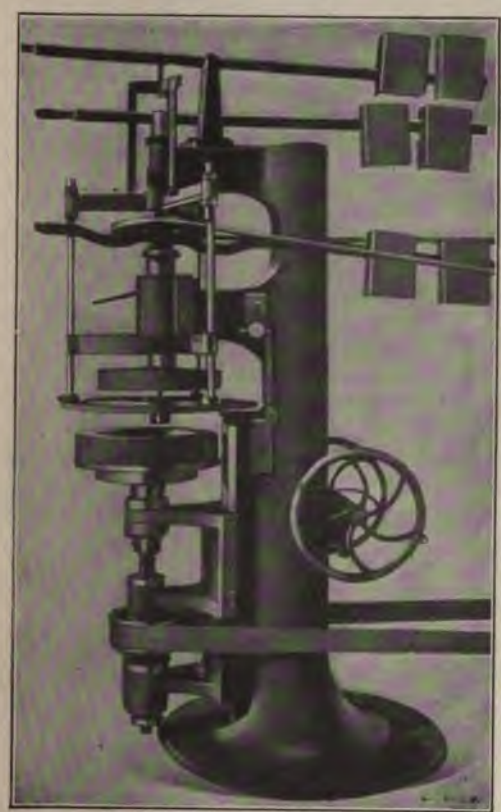


Fig. 21. Richardson's Ball Grinder

Mr. Richardson then made a trial machine which worked very satisfactorily, but as a photograph of this machine was never made, no record of its appearance is preserved. In 1878 he went to England and sold the English patents to Mr. Wm. Bown. A sample machine, as shown in Fig. 21, was made at this time. The patent held by Mr. Richardson did not, however, properly cover the invention, so that he was unable to get full returns for his efforts. The only claim of any importance which he held was as follows: a ring of balls in a V-groove,

revolved by a driving ring and exposed to an emery wheel. This claim was the direct result of his experiments, and by itself was very far-reaching. It gave the ball makers, who soon began to spring up all over the country, a great deal of trouble in their efforts to "go around" it.

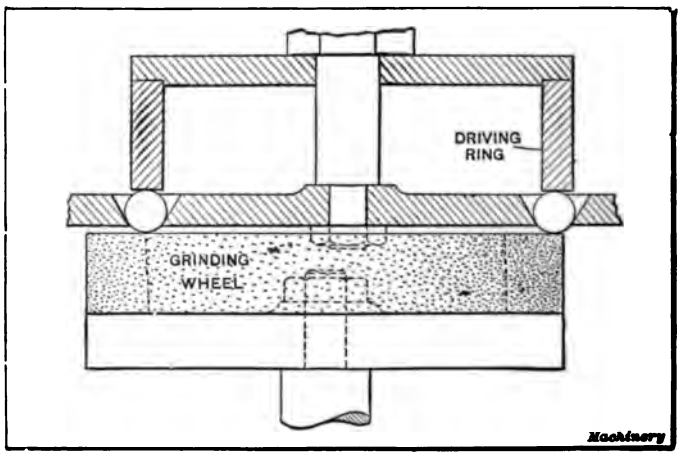


Fig. 22. Diagrammatical View of Principal Arrangement in the Richardson Ball Grinder

As shown in Fig. 21, the emery wheel is placed on the lower spindle which is mounted in the movable head; this head is operated by the handwheels at the rear of the machine. The emery wheel is eccentric

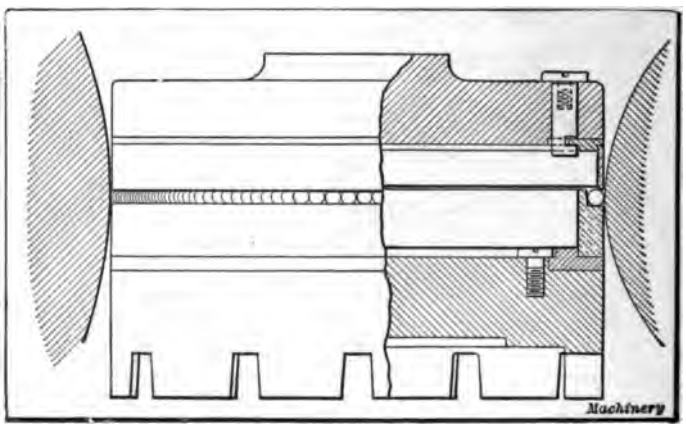


Fig. 23. Principle of the John J. Grant Rough Grinder—U. S. Patent No. 535,794

with the top ring, so that the whole surface of the wheel will successively come in contact with the balls. This keeps the wheel in perfect shape. The V-groove in which the balls rest is formed by two annular

rings or plates (see diagrammatical view in Fig. 22); the outer one is held and adjusted by three long bolts (shown in Fig. 21), while the inner plate is fastened to a rod which passes through the drive shaft to the top of the machine. This inner plate is operated by the middle lever shown, so that the balls thus can be "dropped" when finished. The driving ring which revolves the balls is adjustable in an up and down direction by means of the lower lever, and is clamped in the proper position by the small lever on the main bearing. This driving ring runs in the opposite direction to the emery wheel; the latter is run at a peripheral speed of approximately 5000 feet a minute.

On account of the fact that the outside of the balls run faster than the inside, as they are driven around by the drive ring, the balls assume a spiral motion, thereby exposing all sides to the emery wheel. An approximately accurate sphere is thus produced.

The John J. Grant Rough Grinder

In 1888 when the Simonds Rolling Machine Co., of Fitchburg, Mass., was grinding balls by the old English method, it could only produce balls which were true within 0.003 inch. This accuracy was considered sufficient at that time. Mr. John J. Grant, who was at that time employed by this company, and who had improved the Simonds rolling machine, proceeded to devise a machine which made it possible to produce balls far superior to any ever made. The principle of his first machine, which was a rough grinder, is shown in Fig. 23. This machine produced excellent work, but was very slow in its operation, as the balls had to travel one-half of the circumference of the groove in the ring without coming in contact with the emery wheel. On balls of smaller sizes, the upper or driving ring was so thin that it was possible to grind but a few balls before the emery wheel would wear it away. As shown in Fig. 23, the balls were held at the periphery of the stationary ring in a V-groove. The drive ring was extended over the balls far enough to drive them, and was driven by a pulley on the spindle which held the drive ring. The speed was not over 60 revolutions per minute. A saddle, which was stationary on the base of the machine, carried the emery wheel heads, each head having two wheels, so that the surface coming in contact with the ball would be as wide as possible. The driving pulley was placed between the emery wheels, all being driven from the same countershaft. The upper or drive ring could be raised by a lever at the top of the machine, and the lower ring could be revolved by throwing out a latch with a foot lever. This allowed the machine to be loaded and unloaded very rapidly. Notwithstanding the fact that this machine was very slow, as compared with the Richardson machine in which the emery wheel was on the balls at all times, it was successful, and it was possible for the Simonds company to produce a ball better than those produced by any other manufacturers, and the company soon controlled the ball trade.

In 1891, the Grant Anti-Friction Ball Co[illegible] formed by Mr. J. J. Grant, and a great many experim[illegible] inding of balls without the V-path and drive rin[illegible] the experi-

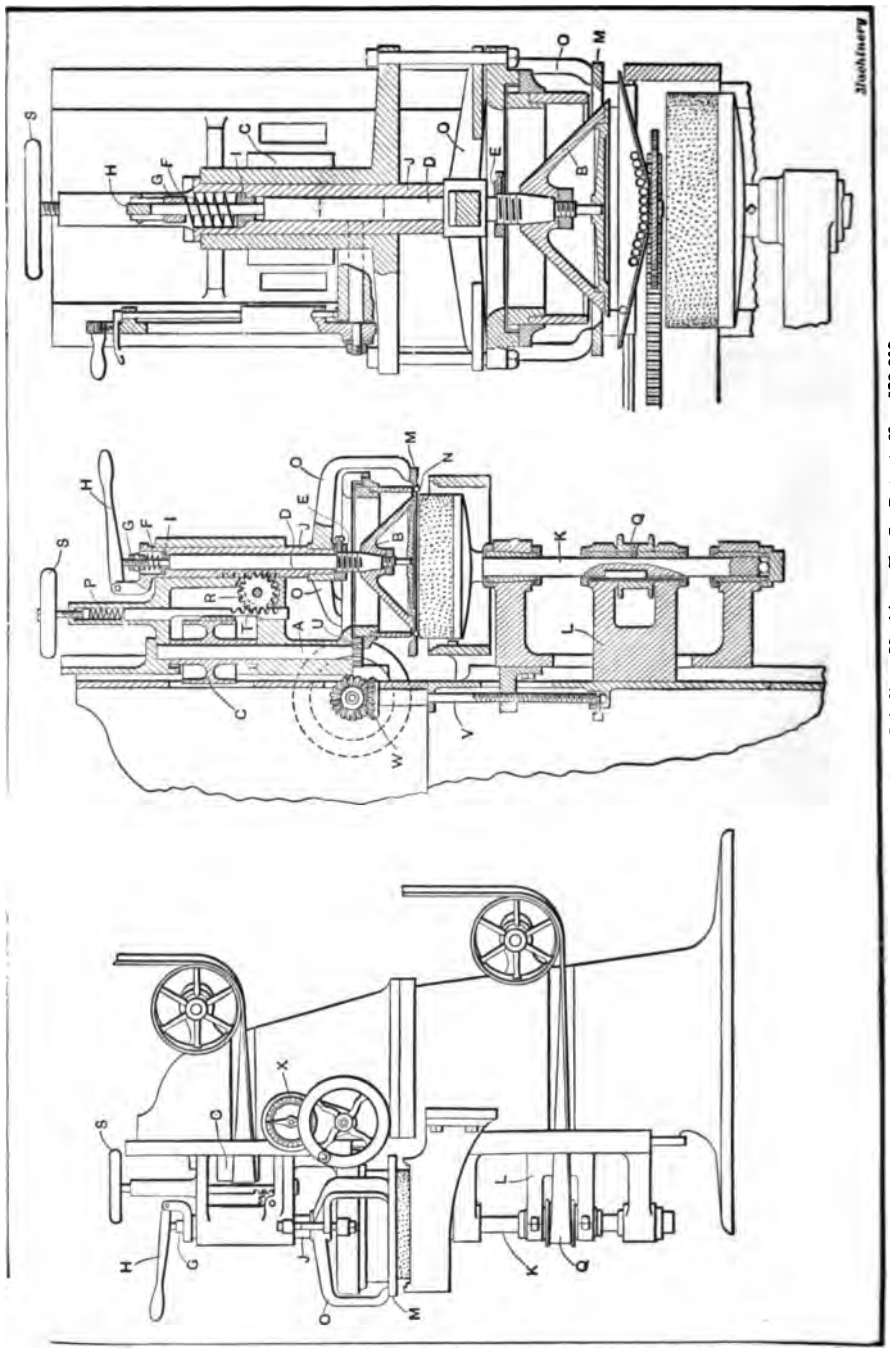


Fig. 24. Robert H. Grant Dry Grinding Machine—U. S. Patent No. 820,019

ments were not successful. It was, therefore, necessary to buy Mr. Richardson's patent, and around this was built the most successful dry grinder ever produced.

The Robert H. Grant Dry Grinder

In Fig. 24 are shown general and sectional views of the R. H. Grant grinding machine, as originally made. It will be seen that the Richardson path is used in a modified form. The drive ring is driven through a gear on the drive ring holder, this gear, in turn, being driven by pinion *U* which is fastened to the shaft *A*. This shaft carries pulley *C* at its upper end. The cone *B* has a plate with hardened segments screwed to its lower end which form the inner part of the race *N*. The cone is fastened to the shaft *D* which is adjustable by collar *E*. On the upper end of the shaft is a spring *F* which is compressed between the collar *I* and the adjustable sleeve *G*. By means of the lever *H*, the shaft *D* can be lowered, thereby allowing the balls to drop into a receptacle after being ground, as shown in the view to the right. On

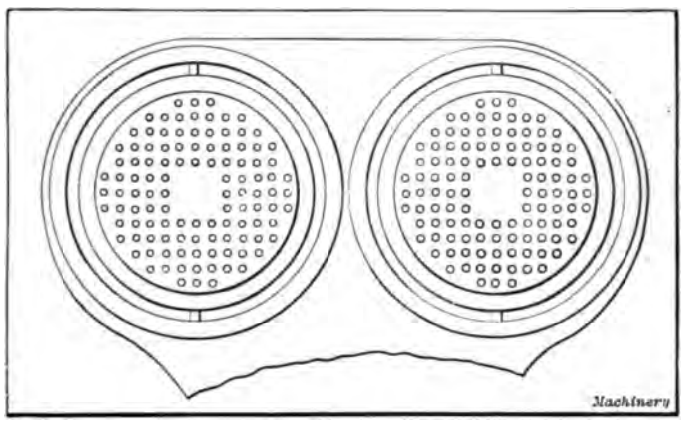


Fig. 25. Arrangement of Balls in the Putnam Grinder

the rear of the quill *J*, which carries the shaft *D*, is cut a rack in which pinion *R* works. The shaft *T* which operates pinion *R* is adjusted by the spring *P*, controlled by the handwheel *S*. On the lower part of the quill *J* is fastened the spider *O* which carries the ring *M*, to which are screwed the hardened segments forming the outer path.

It will be seen that when the rough forgings are placed in the V-path, the driving ring is stationary, but the inner ring can vibrate on account of the action of the spring *F*. The outer ring *M* is permitted to vibrate slightly through the means of the spider *O*, quill *J*, pinion *R* and spring *P*. In this way the rough forgings will be ground only on the high spots until the balls become round.

The loading and unloading is done without stopping. When the balls are finished, the emery wheel is lowered and a pan is pushed under the path of the balls. The handle *H* is pulled down, thus allowing the balls to fall into the pan. The spider *O* is then lowered by

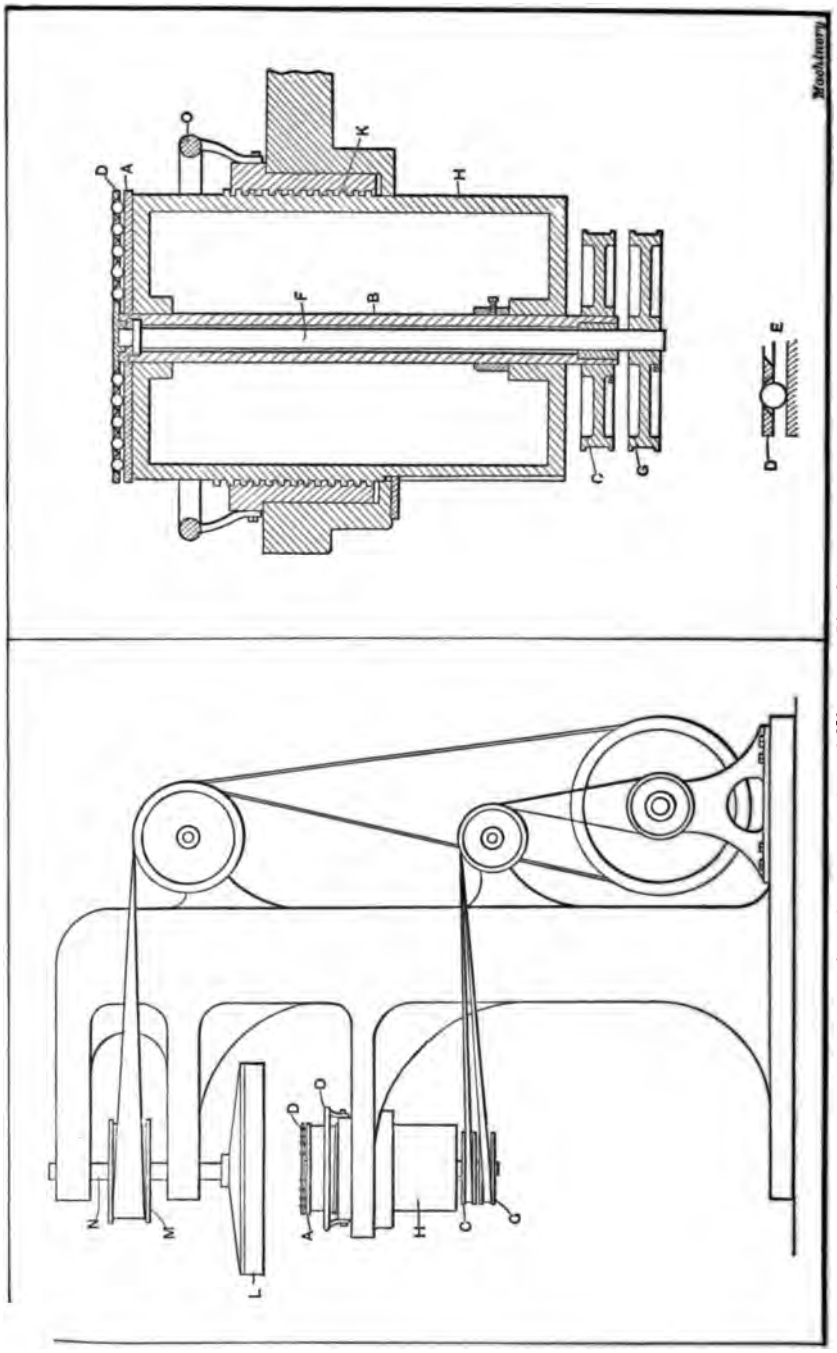


Fig. 26. The Putnam Dry Grinder—U. S. Patent No. 664,823

Fig. 27. Details of Principal Parts of the Putnam Grinding Machine

means of the lever on the end of the shaft carrying pinion *R*. This allows the balls to be ground to be fed into the path *N*, and permits the grinding to commence without interruption.

The emery wheel, which is eccentric with the path of the balls, so as to allow the balls to successively cover the whole surface of the wheel, is carried by the lower head. The spindle *K* carries the pulley

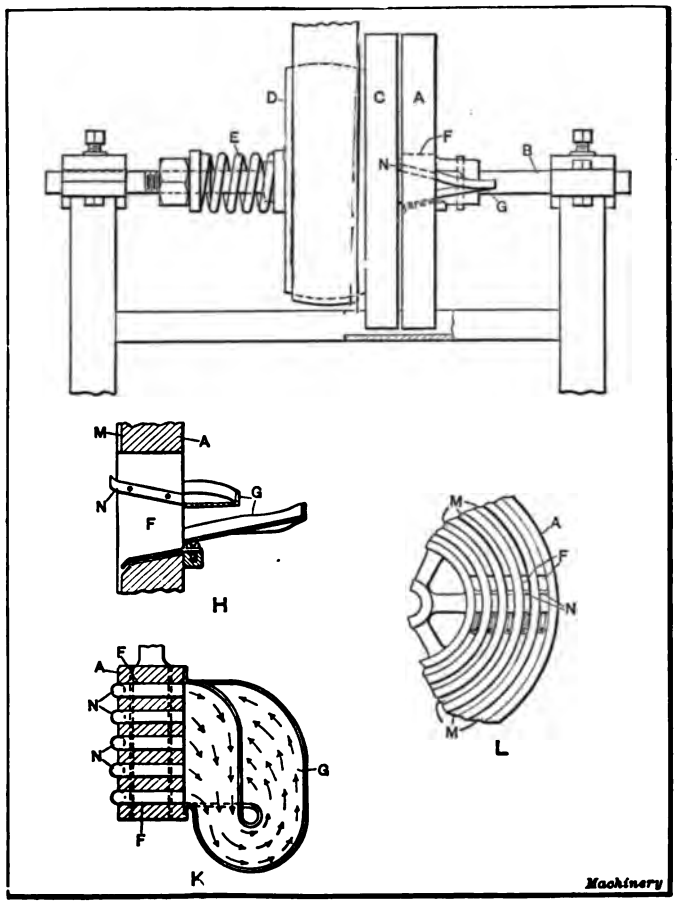


Fig. 28. The Hoffmann Ball Grinding Machine—U. S. Patent No. 803,164

Q which is driven by a belt running over idlers to the countershaft above. Head *L* is raised and lowered by the screw *V* and the bevel gears *W*. The indicator *X*, having a pointer as shown, is connected to this mechanism, and shows the operator how many thousandths inch more he must remove from the balls. With the introduction of this machine the cost of making balls was cut in two, and the quality obtained was far superior to anything which had so far been produced.

The Hawthorne Method of Rough Grinding

About the time when the writer had designed the machine just described, the Hawthorne Mfg. Co., of Bangor, Me., decided to enter into the manufacture of steel balls. This company originally manufactured boot calks and other lumbermen's supplies. Some articles were manufactured for this concern by the Simonds Rolling Machine Co., and representatives of the company frequently visited the Simonds plant. They observed the great number of balls that were beginning

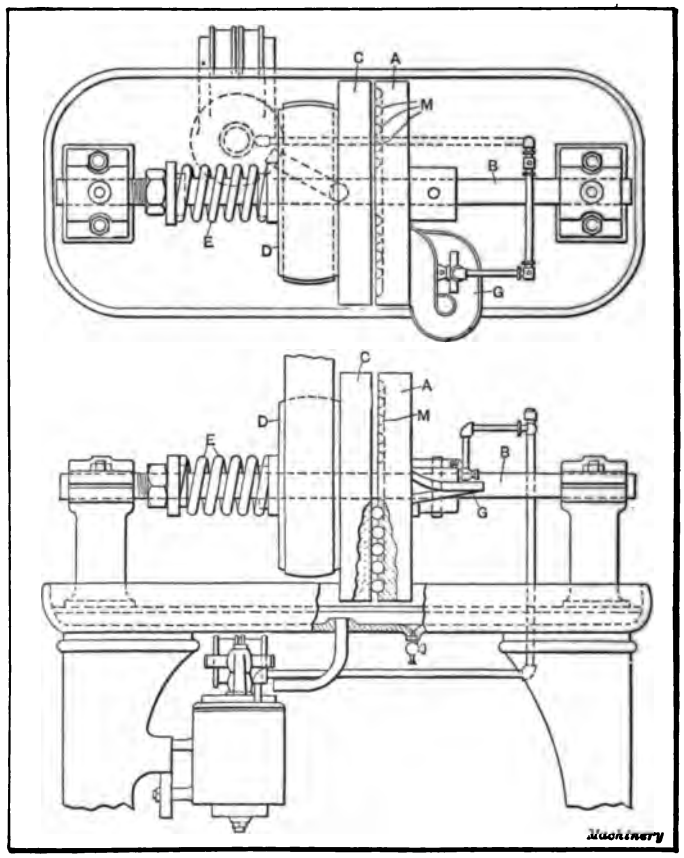


Fig. 29. Improved Hoffmann Ball Grinding Machine—U. S. Patent No. 868,926

to be used in this country, and hence concluded to enter into this field. The first grinder employed by this company made use of sand instead of emery. A bed of sand had been found in which the grit was so hard that it would cut the surface of a ball and last for a considerable length of time before being pulverized. The grinding was done in a closed path in which water and sand were used freely. The sand was fed from bins overhead, and washed out by water when pulverized.

This was a very cheap process, as far as the grinding material was concerned, but did not produce a perfectly spherical blank. The oil or finishing grinders had to be relied upon to round up the balls, and a great many seconds and thirds were produced. The process was applicable, however, to the small balls mostly used at that time, nearly all balls being employed in bicycles. For larger balls, such as are now used in automobiles and other machines of the present day, these machines would have been useless.

The Putnam Ball Grinding Machine

About 1899, Mr. H. M. Putnam, who for several years was connected with the Simonds Rolling Machine Co., started the Fitchburg Steel Ball Co., and invented a dry grinder, as shown in Figs. 25, 26 and 27. This machine, which had to be constructed without the Richardson path, was made in the following manner: The lower plate *A* which corresponds to the drive ring, was driven through the tube *B* which carries the pulley *C*. The plate *D* which is countersunk as indicated at *E*,

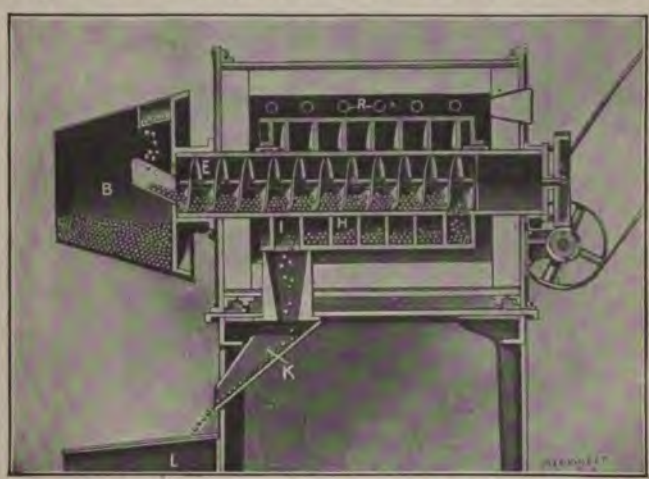


Fig. 30. Section of Ball Heating Furnace, made by the American Gas Furnace Co.

Fig. 27, (see also Fig. 25) is made from saw steel and hardened; it is then forced onto spindle *F* which carries pulley *G*. The cylinder *H* is adjustable by means of the screw thread *K*, and can thus, by means of handwheel *O*, be raised or lowered by the operator so that the balls will come in contact with the emery wheel *L*. This wheel is fastened to the upper spindle *N*, which is driven from pulley *M* by a belt passing over two idler pulleys to the countershaft on the floor, as shown. This machine is very simple, but it does not grind an accurate ball on account of the balls being at various distances from the center, thereby giving them different rates of speed. The outer balls are ground faster than those at the center, and thus balls of all kinds of diameters and degrees of accuracy are produced. The balls are not held firmly in the path as in the Richardson grinder, but are simply confined in the

countersunk holes so that they will not be thrown from the plate. This allows the ball to take its own course, and it becomes badly out of round during the grinding process. The writer is of the opinion that this machine might have been improved, but the company discontinued business soon after the machine was built.

The Chicago Steel Ball Co.'s Grinder

About the same time the Chicago Steel Ball Co., of Chicago, Ill., brought out a dry grinder which had several good features, and which was somewhat similar in operation to the well-known Hoffmann machine which will be described in detail in the following. The Chicago Steel Ball Co.'s machine had the emery wheel and the drive wheel placed in a vertical position. There were several concentric circular paths on the drive ring, and the balls were transferred from one into another,

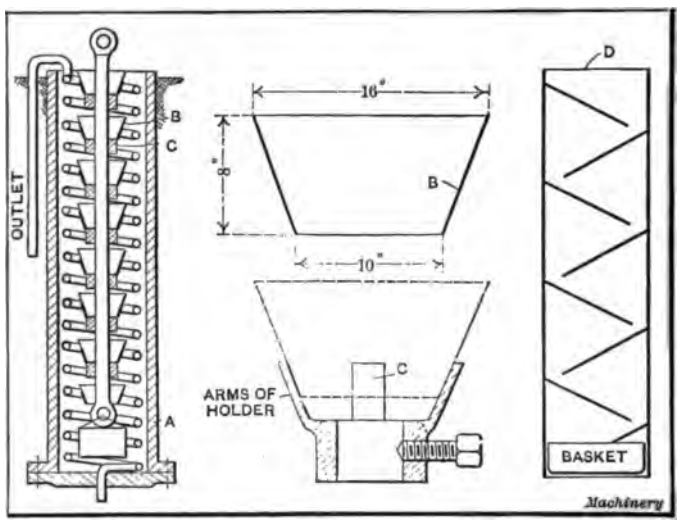


Fig. 31. Tanks used for Quenching Balls

thus giving the balls a different spiral motion on account of being at various distances from the center. This machine ground a very accurate ball, but on account of its poor construction and the poor method used for transferring the balls from one path to another, it was but little used, and, therefore, had no particular influence on ball manufacturing methods.

The Hoffmann Grinder

What may be considered as one of the best ball grinding machines constructed was invented in 1905 by Mr. E. G. Hoffmann, who was at that time connected with the Hoffmann Ball Co., in England. This machine required several years for its development, but when completed it produced a very accurate ball, and is greatly appreciated by ball manufacturers.

In the preceding chapter, the Hoffmann ball turning machine was

described. The blanks produced by this machine are accurate, and but little grinding is required on them. These balls, therefore, are especially suited for grinding in the Hoffmann grinder, as this machine is very slow, and cannot be used to advantage on pressed blanks or forgings, unless they have been previously rough ground by some other process. The machine is automatic, and requires little or no attention, except for gaging the balls at intervals during the grinding. The

Fig. 32. General View of the Grant Dry Grinding Machine, with Samples of Largest and Smallest Balls ground in it

machine requires from three to five hours for removing 0.001 inch on a ½-inch ball.

In Fig. 28, diagrammatical illustrations of the Hoffmann machine as originally designed, are shown. Pulley *D* is driven by a belt from the countershaft, and revolves upon a stationary shaft *B*. The pulley is fastened to the disk *C* which has a series of grooves in its face. Plate *A*, which also has a series of concentric grooves to correspond with those on disk *C*, is stationary and is fastened to shaft *B*. The balls are placed in the machine so as to fill all the concentric grooves, spring *E* forcing disk *C* against plate *A*, thus holding the balls in place. The machine is then started, and the balls, by means of the mixer and

interchanger shown in two views at *H* and *K*, are changed from one groove to another.

As indicated at *H*, *K* and *L*, slots *F* are cut through the stationary disk, a slot being directly opposite each of the grooves *M*. In each slot is placed a finger *N* which projects slightly beyond the bottom of the groove into the corresponding groove in the rotating disk *C*. The function of the finger is to stand in the path of the balls so as to positively dislodge each ball from the groove as it reaches the point where the finger is located. Each finger discharges the ball from the

Fig. 33. Special Grinding Machine used for Grinding the Segments for the Path of the Balls in the Machine shown in Fig. 32

corresponding groove upon a table *G* which affords a surface upon which the balls may roll, and which also directs the balls back toward the grooves below the fingers, the table being slightly inclined toward the lower portion of the slots *F*. It will be seen that this keeps the balls moving from one groove to another so as to place them at different distances from the center at each revolution of plate *A*. This results in the grinding of a very accurate ball.

The grinding is done with oil and emery introduced in the required quantities upon the table *G*, and fed into the machine by the balls. This machine was further improved by the introduction of an emery wheel in place of the grinding ring *C*. The improvement was very marked, as the grinder *C*, when made of cast iron, was apt to be spongy,

and softer in some spots than in others; it would, therefore, quickly wear out of shape. The replacing of this disk by the emery wheel overcame these difficulties. Kerosene oil is used to keep the grooves clear of the loose particles of abrasive material, and prevents the balls from being badly scratched or cut. A very peculiar fact about this grinder is that the emery wheel is run at only 75 revolutions per minute, instead of at the peripheral speed of 5000 feet, generally required by emery wheel manufacturers.

Annealing and Hardening

After the balls have been rough ground so as to remove all scale and decarbonized surface resulting from the forging operation, they are

Fig. 34. The Oil Grinders

taken to the hardening room where they are first annealed. This annealing removes any internal stresses caused by forging or other methods of blanking. The process, as indicated in Fig. 30, is automatic. The balls are fed into the hopper *B* which is revolved by a worm and worm-wheel placed at the opposite end of the machine. From this hopper the balls are fed into the spiral *E* which they follow until they reach the opposite end, where they drop into the outer spiral *H*, which is revolved in the opposite direction. Finally the balls fall out of the cylinder at *I* into the funnel *K*. The machine is heated by gas with burners at *R*, thus preventing the heat from coming into direct contact with the balls and decarbonizing the surface.

After being annealed, the balls are put through the same machine to be heated for the hardening. They are heated to exactly 1275 degrees F., the temperature being determined by a pyrometer. The thermo-couple is placed near the point where the balls leave the cylinder.

The smaller balls are dropped into a reservoir of oil, while the larger ones are immersed in brine. The oil reservoir, shown at *A* in Fig. 31, consists of a length of 30-inch water pipe, one end being provided with a head strongly bolted to it so that it is water-tight. The pipe is sunk into the ground so that the top can receive the balls, as indicated at *L*, Fig. 30. Inside of this cast-iron pipe is placed a coil of 1¼ inch water pipe, in which cold water is circulated in order to keep the bath cool. A rod with a number of inverted galvanized iron cones *B*, adjustably fastened onto the rod by the holders *C*, is then placed in the bath. (Parts *B* and *C* are also shown in detail in Fig. 31.) When the balls drop into the bath in the pipe, they strike the side of the upper cone, which shoots them off at an angle until they strike the opposite side of the next cone; this reverses their direction of motion, so that they reach the basket at the bottom in a zigzag path, thoroughly cooled off. When the balls are thus cooled off, the rod with the basket at the lower end is pulled out, and the balls in the basket are allowed to drain, the oil draining back into the pipe.

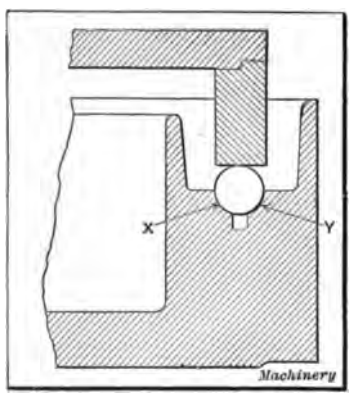


Fig. 35. Illustration of Principle of Action of Oil Grinders

The best oil for the hardening of balls is cotton-seed oil; while it is very expensive, it has sufficient body to cool the balls thoroughly, and it does not need to be replaced. It is only necessary to add to it, from time to time, due to the loss from evaporation.

The larger balls are hardened in brine. The machine shown in Fig. 30 is placed at the edge of a tank of the type shown at *D*, Fig. 31. This tank has a series of shutters made in the from of steps overlapping each other as indicated. These steps force the balls to traverse in a zigzag path through the brine in the tank for a considerable time before dropping into the basket at the bottom.

The largest balls are heated for hardening by being placed on the tiling of a regular casehardening furnace, similar to that made by the Brown & Sharpe Mfg. Co., and are allowed to heat slowly through to the center, the balls being revolved gradually. Two or more balls, according to size, are then placed in a wire basket and rapidly swung to and fro in the brine tank until thoroughly cooled off. All balls, as soon as they are taken from the hardening tanks are placed in a kettle of boiling soda, not only for the purpose of washing them, but also to

prevent the air from coming in contact with them at a time when they are extremely hard. The balls are then placed in the drawing kettles, which are filled with oil heated to 325 degrees F.

Finish Grinding

The balls are now ready to return to the finish dry grinding department, where the same machine as shown in Fig. 24 is used (except that a finer grade of emery wheel is employed) to reduce the balls to the proper size for the oil grinders. For this finish dry grinding the inner and outer segment are ground true, so that the path formed is a perfect track for the balls.

In Fig. 32, the improved Grant machine (Fig. 24) is shown, with the two extremes in size of balls which this machine will grind. In Fig. 33 is shown the special grinding machine which is used for grinding the segments that form the path for the balls. These special grinders are very simple in construction, the wheel head being solid and the spindle on which the segment plate is fastened being driven by a worm through a shaft from a pulley in the rear. The two adjustments up and down and in and out are operated by the shafts which project in the front. By this grinding, the segments are made absolutely true, and by grinding the drive ring by the emery wheel on the machine on which it is used, the balls will make contact on three points absolutely true with each other, and hence the balls produced will be absolute spheres, ready for the final oil grinding.

Fig. 34 shows the ordinary type of oil grinders. These are usually placed in groups of three. The machines are provided with a quill, on which a rack is cut for raising and lowering the head by means of the lever shown projecting at the front of the machine. The machines run about 450 revolutions per minute. The oil grinding constitutes the final finishing operation, and requires considerable skill. The operator must know just how much oil and emery to use, and how long to run the rings so as to make the balls round up.

Assume, for example, that a man is to finish grind balls ¼ inch in size. In Fig. 35 is shown a diagrammatical section of the grinding rings. The circular path of the balls is usually 16 inches in diameter. A half circular groove is cut in the bottom ring, as indicated, and a small channel is cut at the bottom of the groove to allow the oil and emery to reach the bottom of the ball. The top ring is simply a cylinder shrunk onto a plate. This plate can be used over and over again, by merely breaking off the cylinder when used up and shrinking a new ring in place. The upper cylinder has a shallow groove in it for the balls. After the balls have been placed in the ring, the oil and emery are poured in, and the upper ring is lowered onto the balls, the machine then being ready to start. The ¼-inch balls should have 0.006 inch left for the finishing operation. The operator gages the balls and sets his clock on the head of the machine as many minutes ahead of the clock in the room as he knows will be required to obtain very nearly the final size. At this time he must stop the head and again measure

the balls. The operator runs three heads, and as each head finishes its work at different intervals, he has ample time to stop any one head and take out three or four balls from different parts of the ring. After washing them in benzine, he measures them with his micrometer, testing both the size and roundness; if not to size, he replaces them and applies the required amount of oil, emery and speed, until he

Fig. 36. Ring Turning Lathe for Dressing the Oil Grinder Rings

obtains a ball that is as nearly perfect as possible in all respects.

The grinding ring should be of porous medium soft cast iron, as the oil grinding is merely a lapping process, and the ring must wear away to allow the balls to round up. On account of the larger diameter at the outside *Y* than at the inside *X* of the balls, Fig. 35, there is a greater peripheral speed at the outside. This causes the balls to move in a spiral path, as they revolve, so as to bring all points of the surface in contact with the ring. The operator, when using a new ring for the first time, must make allowance for the ring not having become penetrated with emery, and also for its being cold. Later the output can be greatly increased. The heads on the grinders must be kept in perfect alignment, so that the balls will be ground on the entire circumference of the rings.

Fig. 36 shows a special ring turning lathe for dressing the oil grinder rings. It is necessary that these rings be free from chatter marks and imperfections of any kind, so that even the first sets of balls ground by them will be perfect; otherwise the first balls would have to be classified as seconds or thirds on account of poor grinding.

CHAPTER III

INSPECTING, GAGING AND TESTING OF BALLS

In the present chapter, the inspection, grading, gaging, and testing of the balls are described, and a few points given for the benefit of the user and purchaser of steel balls.

The Burnishing and Tumbling Processes

When the balls come from the oil grinders, they have a dull finish and must be burnished or tumbled. The burnishing can be done in the oil grinder with a set of rings having grooves in them the exact size of the balls. A light oil is used, and after a very short run of the machines, a finely polished surface will be produced. This process, however, is expensive, and the ordinary tumbling method is most generally used. The tumbling barrel universally adopted is of the regular iron tilting type. The balls are placed in the barrel in sufficient quantities so that, when they roll over and over, their weight will cause enough friction between them to polish them. A polishing material is placed in the barrel, and the latter is allowed to run at least ten hours to produce a good surface. The balls are then cleaned off by tumbling them in sawdust, and later placed in another barrel with finely cut kid leather. This final tumbling brings out the high polish.

Inspection

The balls are now ready to be inspected, which is done almost exclusively by girls. The skill and rapidity which can be obtained in doing this work is certainly most remarkable. One girl can inspect fifty thousand ¼-inch balls in ten hours. This inspection is done on glass plates which are about ten inches square and inserted in a frame so that the balls cannot roll off. The under side of the glass is painted so as to reflect the light. The plate is about half filled with balls and is placed upon a box which is titled slightly towards the inspector. This causes the balls to always roll to the front. The inspector holds in her hand a magnet resembling in shape a knitting needle. The end is sufficiently magnetized to raise one ball of the size being inspected from the glass. In the other hand the inspector holds a piece of heavy white paper 4 inches wide by 8 inches long, which sheet slides under the balls. This makes the balls revolve, and with the magnet defective balls are picked out. The defects consist of pits, bands, dents, scale, rough grinding marks, etc.

The different grades are separated in boxes, placed to the right of the inspector, and they are [illegible] purposes according to the requirements pl[illegible] evident that different grades of balls may [illegible] that ball bearings are employed in s[illegible] ich as bicycles, clothes-wringers,

After the balls have been inspected for defects they are rolled back and forth on the glass plate in order that those that are out of round may be picked out. As the balls which are not perfectly spherical will take a zigzag motion when rolling down the plate, and the true balls will run straight, it is comparatively easy for the inspector to pick out the imperfect ones. An expert inspector does not stop each time she picks up a ball to place it in the boxes, but will usually toss it into the palm of her hand, which will generally hold all of one grade that she will pick out from the batch of balls on the plate. Balls larger than ¾ inch in diameter are generally taken up by hand and looked over. Those that are out of round in the larger sizes are taken out while measuring the balls.

Grades of Balls

Balls are generally graded into four main classes, known as alloy, and A, B, and C grades. The steel for the alloy balls contains chromium, and these balls have the greatest crushing strength. They must be absolutely free from defects as regards material and finish, and must not vary in size more than 0.0001 inch. Balls classified as A-grade are made from high-grade tool steels, accurately finished, and thoroughly inspected, and must not vary over 0.001 inch above or below the exact dimension. The balls known as B-grade are the seconds taken from the two higher grades mentioned. These are the balls which show slight, almost invisible, defects, and which vary from 0.001 to 0.002 inch. The C-grade, commonly known as hardware balls, are those picked from the higher grades when these show a defective surface. Whether these balls are gaged or not depends upon the use to which they are to be put.

The Gaging of the Balls

After the inspection, the balls are automatically gaged, the gaging being done in a gaging machine in which the balls are fed from a hopper and allowed to roll down between two hardened straightedges and to fall into tubes which carry them to the proper drawer, as indicated in Fig. 37. This illustration shows the Grant ball measuring machine. At *A* is shown the automatic dropping machine, and at *B* the delivery spout through which the balls drop into the measuring slides *C*, provided with a longitudinal slot or opening *O* between them. The sides of the slot may be accurately separated any desired amount by the micrometer adjusting screws provided at both ends. Consequently, the flare of the slot may be adjusted so that it is possible to determine exactly what the diameter is of the balls that will drop into each of the tubes and drawers beneath the measuring slide as the balls roll down along it.

As is clearly shown in the illustration, pockets are arranged successively beneath the inclined slot, and are connected by pipes with the drawers of the cabinet underneath. It is evident that in this way all balls of the same size will go into the same drawer, and that no balls larger than those that go into the middle drawer will

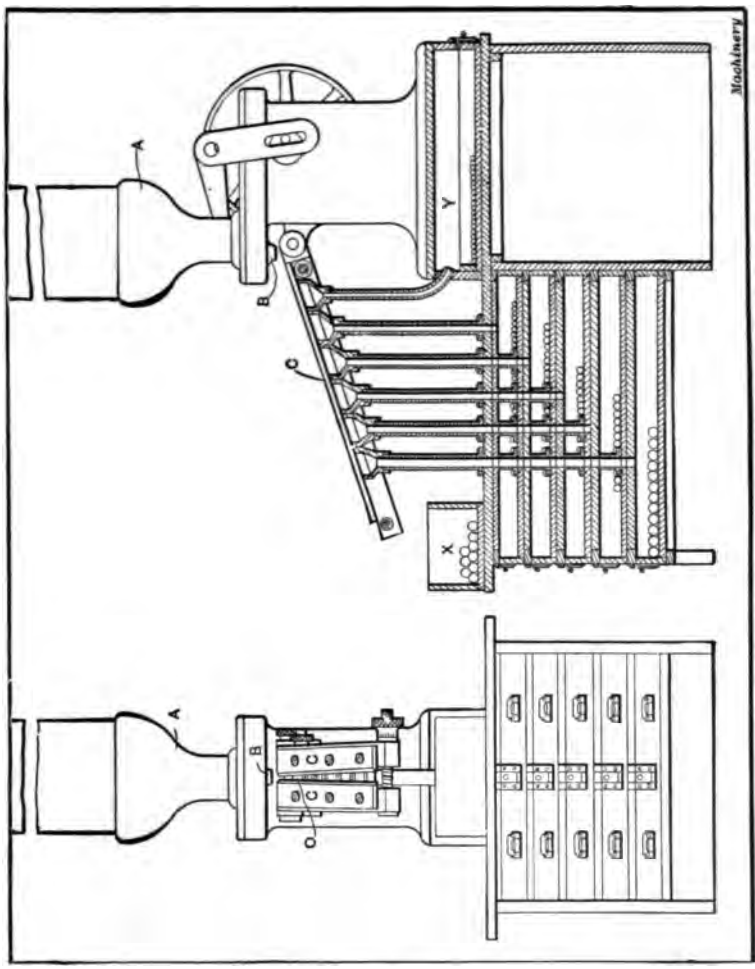


Fig. 37. The Grant Ball Measuring Machine—U. S. Patent No. 833,466

go into the upper drawers being those that are too small, while the large balls will go into the lower drawers. The balls that are entirely too large will run down the full length of the measuring slide and will be deposited in the box *X*. Those that are deposited in the drawers of the cabinet will be from 0.0025 to 0.005 inch too large or too small, according to the setting of the slides.

The exact arrangement of these measuring devices varies somewhat. In Fig. 38 is shown a group of the type of machines just described. ck is run through the center of the machine. In this rack, directly hopper, there is a hole having a bushing in it of the size gaged. The ball drops from the hopper into this bush- forward until it comes to an opening which is con-

nected with a tube for carrying the ball to the measuring slides. The rack is operated by a sector of a gear mounted on a shaft having an eccentric pin on one end and a pulley on the other. Inside of the hopper there is a small tube which is operated up and down by two levers, one being attached to the eccentric pin and the other to the tube. This arrangement prevents the balls from clogging so that the bushing in the rack is always ready with a ball to carry forward, thereby constantly feeding balls to the measuring slides.

In Fig. 39 is shown a Grant machine with the measuring slides removed. This particular machine is worked by a worm and worm-wheel instead of by a rack. There are two disks, beneath the balls in the hopper, the upper one of which is keyed to the shaft fastened to the worm-wheel and hence revolves. This disk has a series of holes

Fig. 38. A Battery of Grant Gaging Machines

drilled near the periphery, these holes being 0.005 inch larger than the ball to be gaged. The lower plate has a hole in it directly above the measuring slide, so that when the upper disk carrying the balls presents a hole directly above the hole in the lower disk, the ball will drop through the hole and tube into the measuring slide. As the hopper is full of balls there is a liability of clogging, because two balls may have a tendency to drop through the hole at once when the opening is presented. The clogging tendency is overcome by a cut-off made of a thin piece of tool steel with beveled edges, which covers two holes in the revolving disk, the holes covered being the one directly over the lower disk and the one next to follow. This prevents jamming of the balls. The remainer of the machine and cabinet is substantially the same as in the machine shown in Fig. 37.

In the Putnam gaging machine the hopper is worked practic

same as in a machine for slotting screws. Fingers raise the ball, allowing it to fall into a trough, and then through a tube onto the measuring slides.

This mechanical gaging and sorting of balls is applied to all sizes up to and including ⅝ inch. The large sizes are measured by hand by micrometers. The girls employed for this work pick them up one by one and measure each ball separately over several diameters, throw-

Fig. 39. A Modified Type of Grant Measuring Machine, with Gaging Slides removed

ing them into small boxes placed before them, each of the boxes containing a certain size of balls between the limits of measurements adopted. This work is very rapidly done, as the operators become very skillful.

Counting the Balls

The next operation is the counting and boxing of the balls which at first sight might be assumed to be a tedious and very slow operation. So it would be were it not for the mechanical means adopted for doing this work. Balls up to ⅜ inch in diameter are counted by means of a counting board, as indicated in Fig. 40, which has holes sunk in it 0.010 inch larger [illegible] the ball. Around the board is tacked a narrow strip of wood to [illegible] the balls from rolling off. The balls are then poured upon the [illegible] all balls which do not find a hole to enter are allow[illegible] is a predetermined number of holes in the b[illegible] knows how many balls she has, and she [illegible] the counting board into a

pasteboard box in which the balls are packed. In this way one girl can easily count a million balls a day and do other work besides.

The pasteboard boxes are made of a telescoping form, lined with paper which is free from acid and which has previously been soaked in an anti-rust compound. The balls, which have a very high polish, would otherwise easily rust on account of sweating, which is caused by the difference in temperature of extreme heat and cold. It is very essential that steel balls should be kept in a room properly heated.

The Testing of Balls

The testing of a steel ball for crushing strength should be done between hardened plates by placing three balls in a tube into which they nearly fit. The center ball is the one that will be tested. The

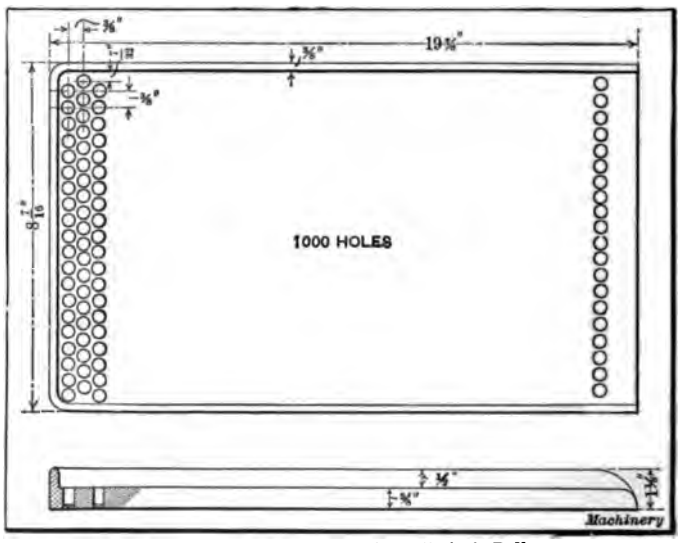


Fig. 40. Counting Board for 5/16-inch Balls

upper and lower balls will, of course, sink into the plates, and this will give them more of a surface bearing than the middle ball, which bears only in two points upon the upper and lower balls; hence the middle ball will ordinarily give way first. As the pressure is applied, a double pressure cone will be formed inside of the ball, this cone having its apexes where the outside balls bear on the middle ball. If properly hardened, a ball will break into several pieces. This method is the proper way to test a ball, but there seldom are two balls that will stand exactly the same load when tested. This is caused largely by the methods in which the ball blank is made. As will be remembered from the description of the making of the blanks in the first chapter of this book, the balls in the forging process are much more compact at what might be called the "poles," that is, where they join the next ball forged, than at the "equator." Therefore, if the center ball

being tested has the point of contact on the "equator," it will not stand within ten or twenty per cent of the load that it would stand if the points of contact were at the "poles." The same method of reasoning may be applied to stamped and turned balls.

Through the means of this testing operation and the appearance of the fracture, it can be determined whether the balls have been properly hardened. Every batch of steel, no matter how carefully made, usually requires a slightly different treatment in hardening, and what this treatment is must be determined by the man responsible for the hardening work. The accompanying table shows the crushing load ordinarily required by ball manufacturers for regular tool-steel balls.

Size of Ball in Inches	Ultimate Strength of Ball in Pounds	Size of Ball in Inches	Ultimate Strength of Ball in Pounds
1/16	390	5/8	39,000
3/32	875	3/4	56,250
7/64	1,562	13/16	66,000
1/8	2,450	7/8	76,000
3/16	3,496	15/16	88,000
7/32	4,780	1	100,000
1/4	6,215	1 1/8	125,000
5/16	9,940	1 1/4	156,000
3/8	14,000	1 1/2	225,000
7/16	19,100	1 5/8	263,000
1/2	25,000	1 3/4	306,000
9/16	31,500	2	400,000

The figures above have been adopted after a great many years of testing and are considered by the manufacturers safe figures with which to calculate. Of course, in selecting a ball for a bearing, a factor of safety of ten should always be adopted unless the bearing is used in an extremely narrow space. The grooves in which the balls run when heavy loads are imposed should be round and not of V-form. No figures can be given relating to tests of balls made from alloy steel, because these steels give such irregular results that the manufacturers have been unable to compile any data that would be in any way satisfactory. It is, however, safe to state that the alloy-steel balls will stand from 25 to 50 per cent more than the regular tool-steel balls.

Balls of Other Materials than Steel

Balls are made of a great many other materials, brass and bronze, for instance, being used extensively for oil-well devices where acid is found in the crude oil. Such balls are also used in valves where the material to be pumped will rust steel balls and cause corrosion, and also in electrical work. German silver balls are used in Yale locks to prevent corrosion when used on shipboard or in other places where they would be subjected to the damp sea air. Casehardened machine steel balls are used extensively in agricultural implements and similar apparatus on account of being inexpensive. Chilled cast-iron balls used in turntables, trucks, and for similar requirements.

Points for the User and Purchaser of Steel Balls

In the following the essential points relating to the manufacture of balls which should be kept in mind by a purchasing agent or consumer are given. Nothing but a tool-steel ball should be used for high-grade work, and it is very important that it be properly heat-treated. Do not be deceived by a finely polished ball, as high polish and deep scratches (which show only under a magnifying glass) do not necessarily indicate a good ball. In fact, the outside appearance has little or nothing to do with the wear of a ball, for a dull looking ball may be just as good as one with the highest polish. The polish is merely the result of the tumbling process.

The first requirement is that the right material has gone into the balls. It costs but little to have the steel analyzed so that the purchaser may know whether he is getting a tool-steel ball or a machine-steel ball. The fact that the ball has only a point bearing makes it the more important that it be made from good material in order to stand the pressure to which it may be subjected. Casehardened machine-steel balls ought not to be used when heavy duty is required. Naturally there is some difference in the quality of the steel that costs thirty-five dollars per ton from that which costs one-hundred-fifty dollars per ton.

It is true that a ball can be casehardened very deeply, in fact, almost through to the center, but it should be remembered that casehardening implies adding carbon to the steel under a high heat, which causes the pores in the steel to open so that the carbon can enter. The process, however, does not remove the injurious elements, such as phosphorus, sulphur and silicon, of which the cheaper steel contains a large percentage. It is, of course, perfectly satisfactory to use casehardened balls for many purposes, but when it comes to a really high-grade article, the highest class of steel is to be preferred.

In order to determine whether a ball has been properly heat-treated, place the finished ball in a piece of waste on an anvil and break it open with a heavy blow. The waste prevents the pieces from flying around. If the ball is properly heat-treated, the break will show a soft silky-appearing surface—the grain of the steel being fine. If it has not been heat-treated, it will look coarse and granular, having more the appearance of cast iron.

If during the test the ball should break in half, it would indicate that it had not been properly drawn after hardening, but was still subjected to internal stresses. If such a ball is placed in a bearing, it will easily break if subjected to a severe shock or strain. If a ball has been properly drawn it can be touched with a fine Swiss file, and under the blows of a heavy hammer it will dent slightly and break into several pieces.

Balls over 5/16 inch in diameter that have been turned or headed should not be used for heavy duty, as they are not as good as balls for which the blanks have been forged. The headed ball, on account of the severe shock to which the metal is subjected when cold, cannot be treated so as to stand the strain that the forged ball will stand. A

turned ball is cut from a rod which is rolled, so that the grain of the steel is in a lengthwise direction; hence when a ball is turned from this bar the surface of the ball consists of a mass of exposed fibers. When put under a heavy strain, as in a thrust bearing, it will pit and flake off. The surface of the ball should be smooth, that is, all the marks from the rough-grinding process should have been removed in the finish-grinding. If this has been done it can be readily determined by a magnifying glass.

A ball made from a forged blank cannot be hardened properly unless the decarbonized surface has been wholly removed. Some manufacturers attempt to keep the forgings as small as possible in order to save material and time in grinding, and in many cases it is then impossible to remove all of the decarbonized surface. Hence when the ball is hardened, rough marks and soft spots can be detected. The soft spots are much brighter than the properly hardened surface.

If balls are to be used for special purposes, this should be designated in the order sent to the ball manufacturer. In order to be able to supply a ball that will give satisfaction, it is necessary that he be furnished with information as to what the ball is to be used for, the speed and load at which it will be used, and the kind of bearing employed. Then the balls can be drawn to a degree of temper adapted to the particular purpose in view, and thus satisfaction can be guaranteed to the purchaser. It is also very important to see that the balls that are furnished are not out of round, as this would cause the bearings to "catch" and "jump." The resulting bearing will run unsatisfactorily, and will rattle on account of the fact that the balls are loose at one point and tight at another. The actual size of the ball does not make a great deal of difference, provided the balls are all of the same size. In other words, in a lot of one-hundred-thousand balls, if they are found to be 0.0005 or 0.001 inch under size they will give satisfaction if they are all used before the next shipment can get mixed up with them.

It has already been mentioned that the temperature of the room in which the balls are stored must not be too low. The temperature of the stock-room should be kept the same at all times, and on Sundays and holidays, when the factory is closed, it should be especially heated, for a ball which becomes very cold and then is brought back to a warm temperature will soon begin to rust and cause a great deal of trouble.

Summary of Ball-making Processes

In order to fix in the reader's mind the various processes that a ball passes through, from the time that the blank is produced from the rough stock until the finished ball enters the stock-room, a general summary of the processes described in the three chapters comprising the present treatise on the manufacture of steel balls will be given.

There are several methods for producing the ball blank. One is that of turning the ball blanks in a special automatic machine. This method is rapid and makes it possible to produce a blank which requires less

grinding than the blanks produced by other methods, but on account of the fact that the fibers of the stock from which the blank is turned are cut and exposed at the surface, a ball so made is of inferior strength after hardening as compared with balls the blanks of which are made by other methods.

Another method commonly used for producing ball blanks is to form the blank in a heading machine. A bar is fed into the machine and pieces of the required length are cut off and headed between dies to a ball shape. This is a very rapid method, and balls up to, say, 5/16 or ⅜ inch in diameter can be made advantageously by this process. As there is no waste, this process for smaller sizes of balls must be deemed the best as well as the cheapest of the methods used at the present time.

The best method of making ball blanks from ⅜ inch to 2 inches in diameter is known as string forging. This method is very extensively used and the balls so produced, when properly heat-treated, are strong and tough in their structure. The balls which have been produced by the heading or forging process must have the fin or flash ground off before they pass to the grinding machines. The process by means of which the fin is removed is called "flashing," and the machine in which it is done is ordinarily termed a "rotary" file. Large balls are flashed separately in a special fixture by an ordinary emery wheel.

The balls are now ready for the dry-grinding process, the grinding being done by an emery wheel acting upon the balls which are held and rotated by suitable means. After being dry-ground, the balls are annealed and then hardened, the smaller balls being quenched in cotton-seed oil, while the larger ones are immersed in brine. After hardening, the balls are washed in boiling soda and then tempered in oil.

After the tempering, the balls are ready to return to the finish dry-grinding department, and are finish dry-ground in machines of the kind that performed the rough dry-grinding, but a finer grade of emery wheel is used. From the finishing dry-grinders the balls pass to the oil grinders, where the final grinding operation is performed and where the balls are brought to exact size. The oil grinding operation is practically a lapping process, no grinding wheel being used. The machine has merely two plates, one of which is grooved, between which the balls roll. The grinding medium is fine emery and oil.

When the balls have been brought to size in the oil grinders, they are given their final finish either by burnishing them in machines similar to the oil grinders, or by being tumbled in a tumbling barrel with a polishing medium. Next they are tumbled in sawdust, and finally in a barrel with cut-up kid leather to obtain the high polish. The balls are then inspected, graded and gaged. The smaller balls are gaged in gaging machines, while the larger are measured by micrometers. Next the balls are counted and packed into boxes and sent to the store-room, which finishes the operations.

No. 67. Boilers.
No. 68. Boiler Furnaces and Chimneys.
No. 69. Feed Water Appliances.
No. 70. Steam Engines.
No. 71. Steam Turbines.
No. 72. Pumps, Condensers, Steam and Water Piping.

LOCOMOTIVE DESIGN AND RAILWAY SHOP PRACTICE

No. 27. Locomotive Design, Part I.
No. 28. Locomotive Design, Part II.
No. 29. Locomotive Design, Part III.
No. 30. Locomotive Design, Part IV.
No. 79. Locomotive Building. — Main and Side Rods.
No. 80. Locomotive Building. — Wheels; Axles; Driving Boxes.
No. 81. Locomotive Building. — Cylinders and Frames.
No. 82. Locomotive Building.—Valve Motion.
No. 83. Locomotive Building.—Boiler Shop Practice.
No. 84. Locomotive Building.—Erecting.
No. 90. Railway Repair Shop Practice.

ELECTRICITY—DYNAMOS AND MOTORS

No. 34. Care and Repair of Dynamos and Motors.
No. 73. Principles and Applications of Electricity. —Static Electricity; Electrical Measurements; Batteries.
No. 74. Principles and Applications of Electricity. —Magnetism; Electric-Magnetism; Electro-Plating.
No. 75. Principles and Applications of Electricity. —Dynamos; Motors; Electric Railways.
No. 76. Principles and Applications of Electricity. —Telegraph and Telephone.
No. 77. Principles and Applications of Electricity. —Electric Lighting.
No. 78. Principles and Applications of Electricity. —Transmission of Power.
No 115. Electric Motor Drive for Machine Tools.

HEATING AND VENTILATION

No. 39. Fans, Ventilation and Heating.
No. 66. Heating and Ventilation of Shops and Offices.

IRON AND STEEL

No. 36. Iron and Steel.
No. 62. Hardness and Durability Testing of Metals.
No. 117. High-speed and Carbon Tool Steel.
No. 118. Alloy Steels.

FORGING

No. 44. Machine Blacksmithing.
No. 45. Drop Forging.
No. 61. Blacksmith Shop Practice.
No. 113. Bolt, Nut and Rivet Forging.
No. 114. Machine Forging.
No. 119. Cold Heading.

MECHANICAL DRAWING AND DRAFTING-ROOM PRACTICE

No. 2. Drafting-Room Practice.
No. 8. Working Drawings and Drafting-Room Kinks.
No. 33. Systems and Practice of the Drafting-Room.
No. 85. Mechanical Drawing.—Geometrical Problems.
No. 86. Mechanical Drawing.—Projection.
No. 87. Mechanical Drawing.—Machine Details.
No. 88. Mechanical Drawing.—Machine Details.

DIE-CASTING

No. 108. Die-Casting Machines.
No. 109. Die-Casting, Dies and Methods.

MISCELLANEOUS

No. 35. Tables and Formulas for Shop and Drafting-Room.
No. 110. Extrusion of Metals.

MACHINERY'S DATA BOOKS

MACHINERY'S Data Books include the material in the well-known series of Data Sheets published by MACHINERY during the past fifteen years. Of these Data Sheets, nearly 700 were published and 7,000,000 copies sold. Revised and greatly amplified, they are now presented in book form, kindred subjects grouped together. The price of each book is 25 cents (one shilling) delivered anywhere in the world.

LIST OF MACHINERY'S DATA BOOKS

No. 1. Screw Threads.
No. 2. Screws, Bolts and Nuts.
No. 3. Taps and Dies.
No. 4. Reamers, Sockets, Drills and Milling Cutters.
No. 5. Spur Gearing.
No. 6. Bevel, Spiral and Worm Gearing.
No. 7. Shafting, Keys and Keyways.
No. 8 Bearings, Couplings, Clutches, Crane Chain and Hooks.
No. 9. Springs, Slides and Machine Details.
No. 10. Motor Drive, Speeds and Feeds, Change Gearing, and Boring Bars.
No. 11. Milling Machine Indexing, Clamping Devices and Planer Jacks.
No. 12. Pipe and Pipe Fittings.
No. 13. Boilers and Chimneys.
No. 14. Locomotive and Railway Data.
No. 15. Steam and Gas Engines.
No. 16. Mathematical Tables.
No. 17. Mechanics and Strength of Materials.
No. 18. Beam Formulas and Structural Design.
No. 19. Belt, Rope and Chain Drives.
No. 20. Wiring Diagrams, Heating and Ventilation and Miscellaneous Tables.

MACHINERY'S HANDBOOK

For MACHINE SHOP AND DRAFTING-ROOM

A REFERENCE BOOK ON MACHINE DESIGN AND SHOP PRACTICE FOR THE MECHANICAL ENGINEER, DRAFTSMAN, TOOLMAKER AND MACHINIST.

MACHINERY'S Handbook comprises nearly 1400 pages of carefully edited and condensed data relating to the theory and practice of the machine-building industries. It is the first and only complete handbook devoted exclusively to the metal-working field, and contains in compact and condensed form the information and data collected by MACHINERY during the past twenty years. It is the one essential book in a library of mechanical literature, because it contains all that is of importance in the text-books and treatises on mechanical engineering practice. Price $5.00.

GENERAL CONTENTS

Mathematical tables—Principal methods and formulas in arithmetic and algebra—Logarithms and logarithmic tables—Areas and volumes—Solution of triangles and trigonometrical tables—Geometrical propositions and problems—Mechanics—Strength of materials—Riveting and riveted joints—Strength and properties of steel wire—Strength and properties of wire rope—Formulas and tables for spring design—Torsional strength—Shafting—Friction—Plain, roller and ball bearings—Keys and keyways—Clutches and couplings—Friction brakes—Cams, cam design and cam milling—Spur gearing—Bevel gearing—Spiral gearing—Herringbone gearing—Worm gearing—Epicyclic gearing—Belting and rope drives—Transmission chain and chain drives—Crane chain—Dimensions of small machine details—Speeds and feeds of machine tools—Shrinkage and force fit allowances—Measuring tools and gaging methods—Change gears for spiral milling—Milling machine indexing—Jigs and fixtures—Grinding and grinding wheels—Screw thread systems and thread gages—Taps and threading dies—Milling cutters—Reamers, counterbores and twist drills—Heat-treatment of steel—Hardening, casehardening, annealing—Testing the hardness of metals—Foundry and pattern shop information—The welding of metals—Autogenous welding—Thermit welding—Machine welding—Blacksmith shop information—Die casting—Extrusion process—Soldering and brazing—Etching and etching fluids—Coloring metals—Machinery foundations—Application of motors to machine tools—Dynamo and motor troubles—Weights and measures—Metric system—Conversion tables—Specific gravity—Weights of materials—Heat—Pneumatics—Water pressure and flow of water—Pipes and piping—Lutes and cements—Patents.

MACHINERY, the leading journal in the machine-building field, the originator of the 25-cent Reference and Data Books. Published monthly. Subscription, $2.00 yearly. Foreign subscription, $3.00.

THE INDUSTRIAL PRESS, Publishers of MACHINERY

140-148 LAFAYETTE STREET NEW YORK CITY, U. S. A.